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(54) **OPTICAL MODULE HAVING CAVITY SUBSTRATE**

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(51) **Int. Cl.**
G02B 7/02 (2006.01)

(52) **U.S. Cl.** **359/811**; 359/819

(58) **Field of Classification Search** 359/819, 359/811; 250/580; 257/9
See application file for complete search history.

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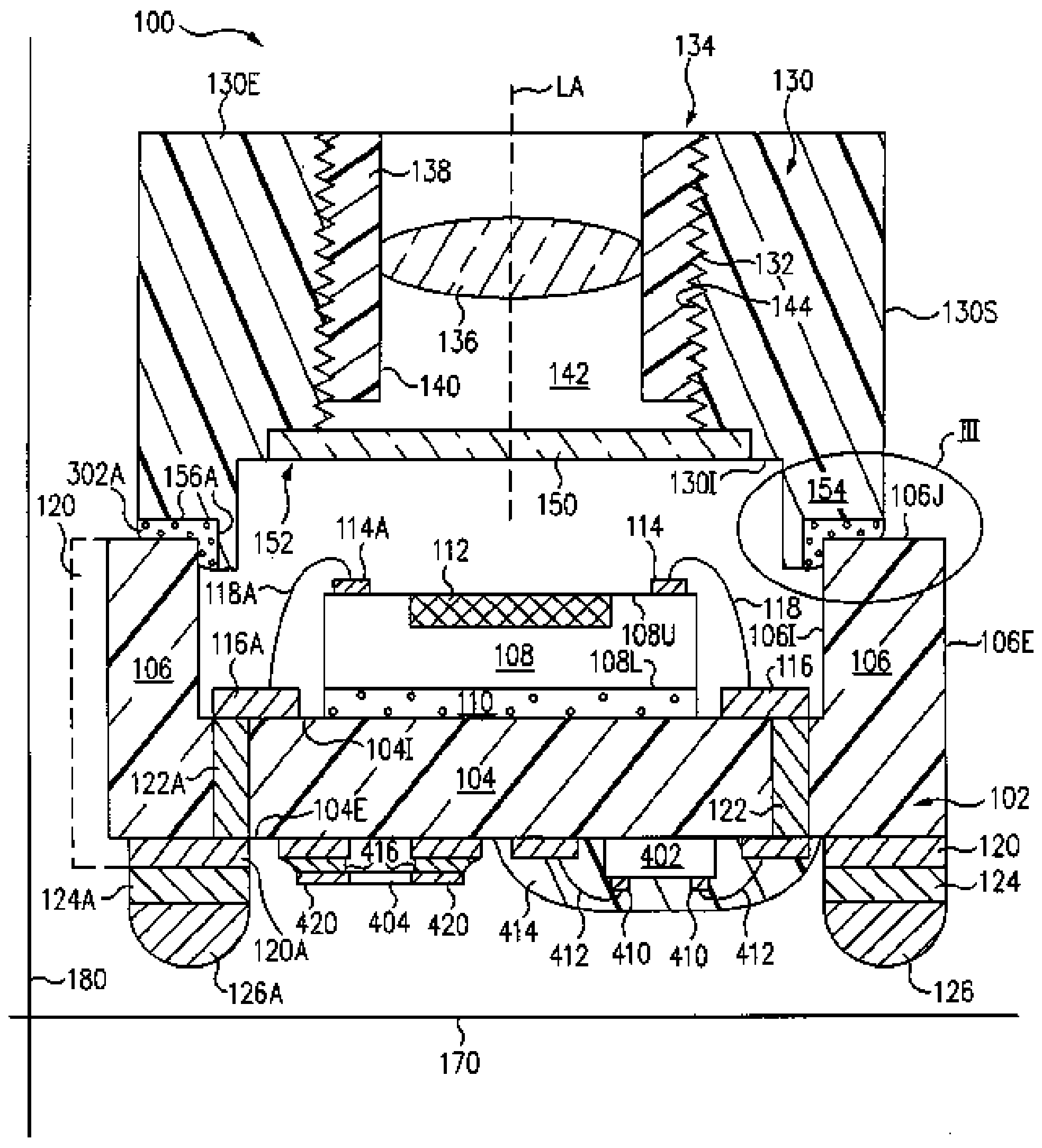
(57) **ABSTRACT**

A method of forming an optical module includes mounting an image sensor to a base of a substrate and bonding a lens housing to a sidewall of the substrate. A mounting surface of the lens housing includes a locking feature having a horizontal surface and a vertical surface. The sidewall of the substrate includes a joint surface. To bond the lens housing to the sidewall of the substrate, a bond is formed between the horizontal surface of the locking feature of the lens housing and the joint surface of the sidewall. Further, a bond is formed between the vertical surface of the locking feature of the lens housing and an interior surface of the sidewall.

16 Claims, 9 Drawing Sheets



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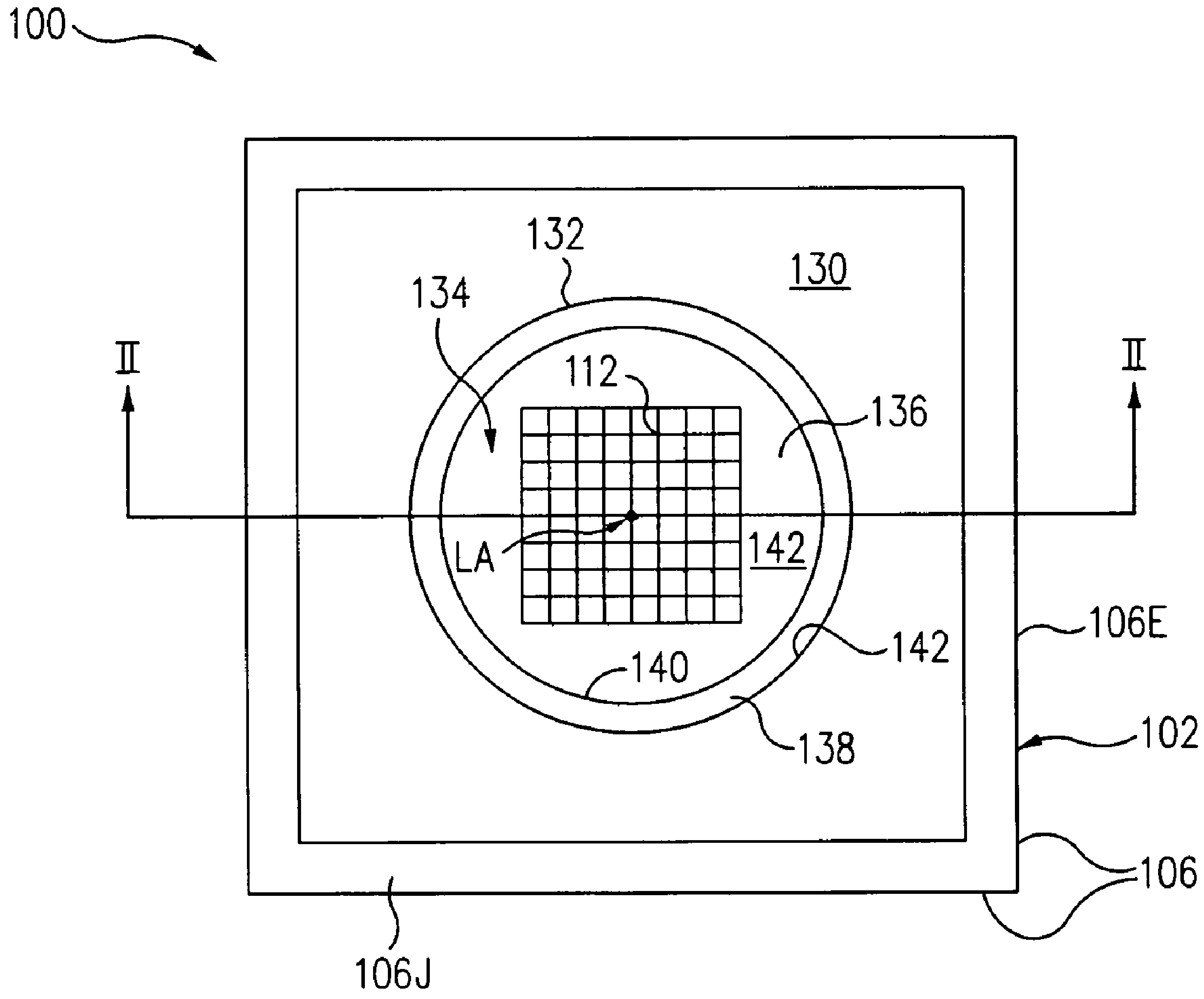
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FIG. 1

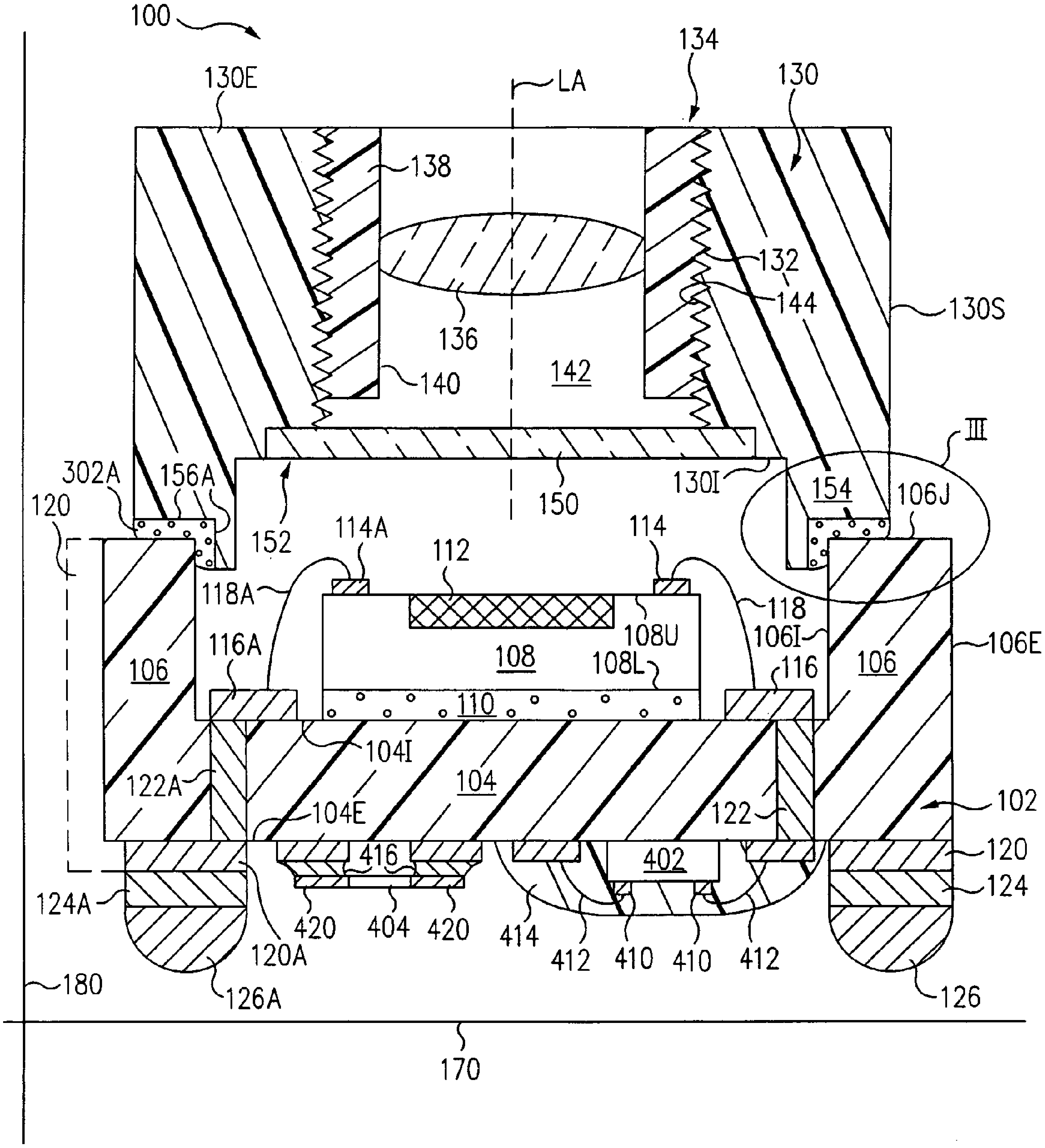
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FIG. 2

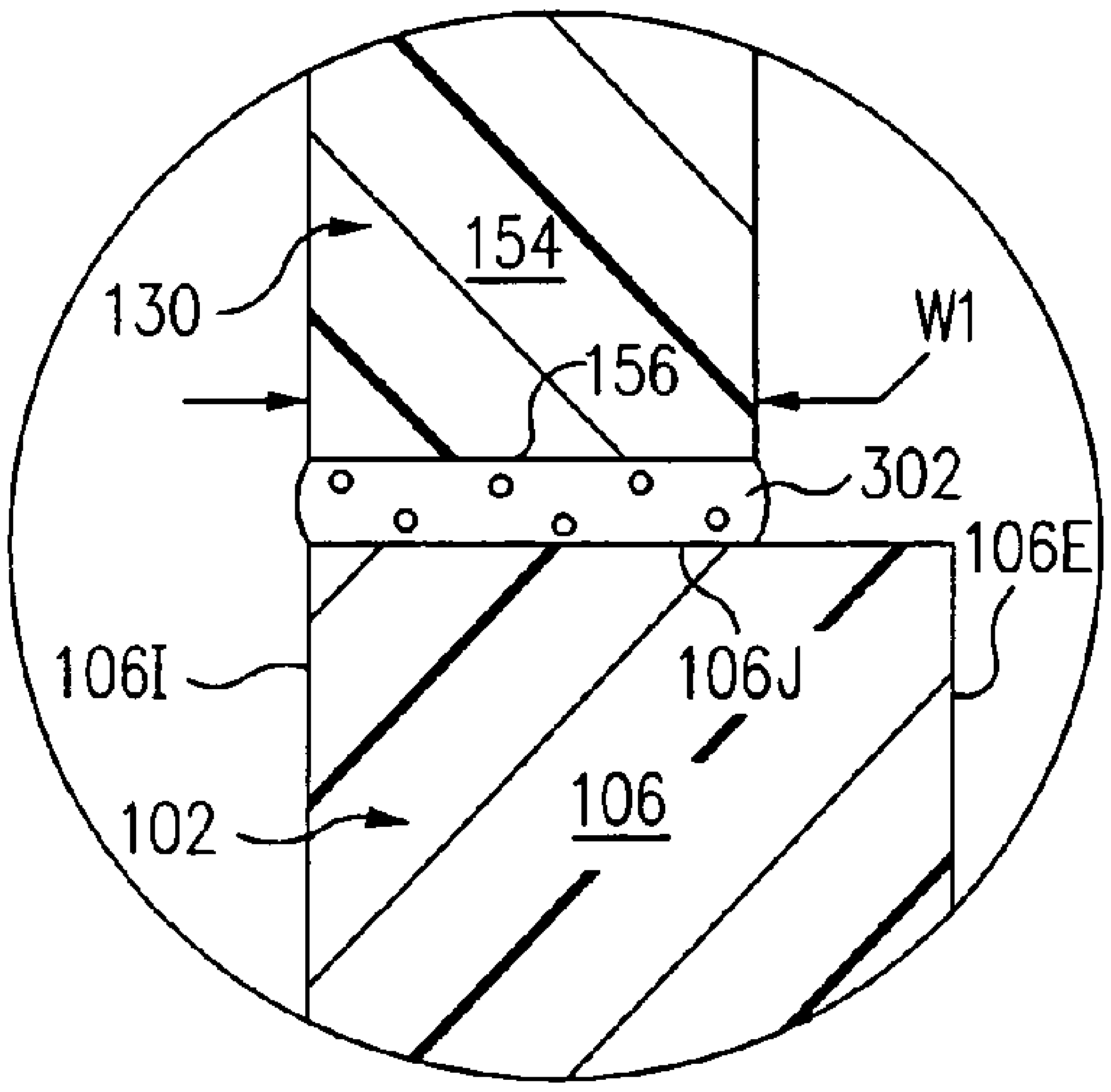


FIG. 3A

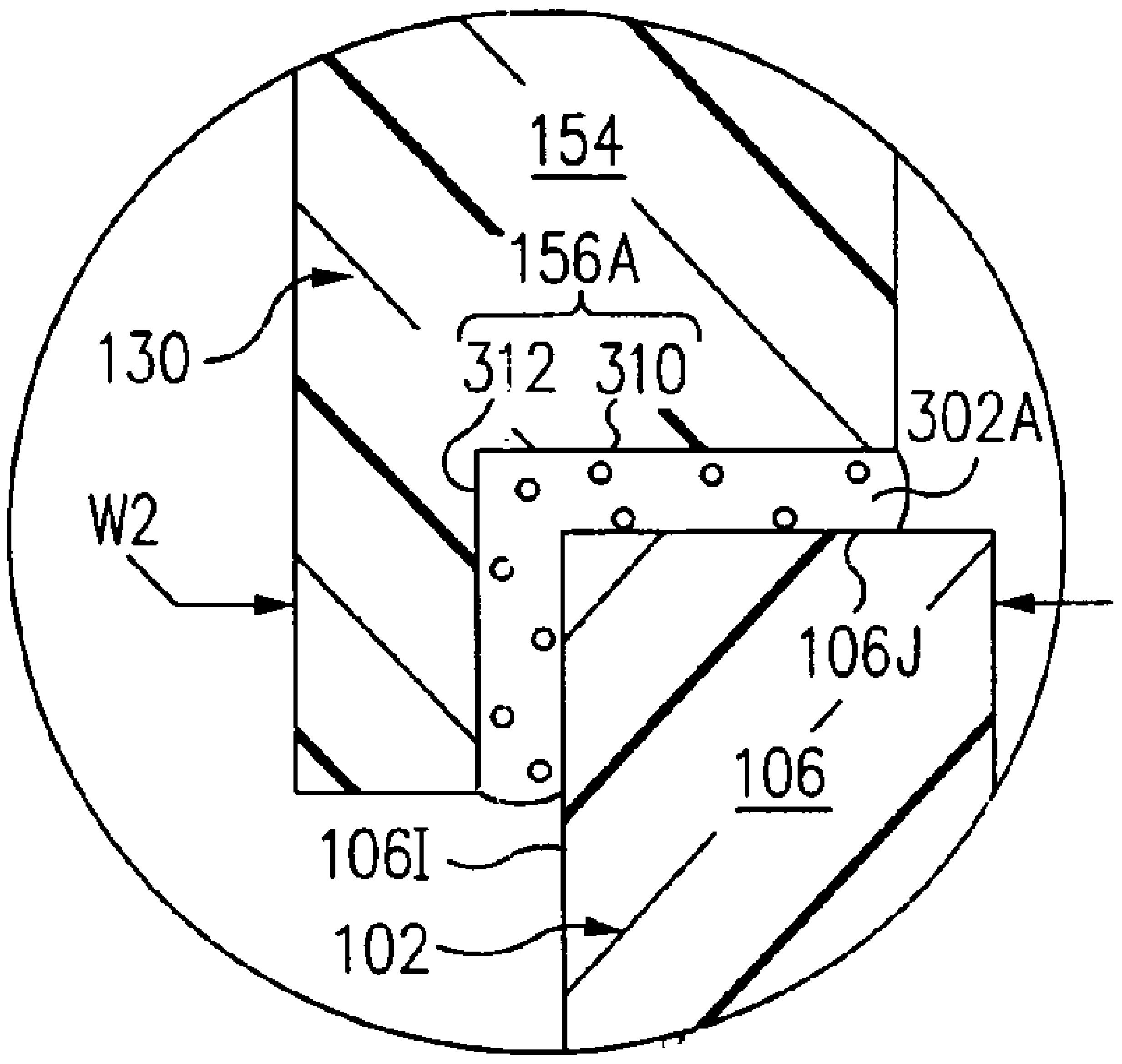


FIG. 3B

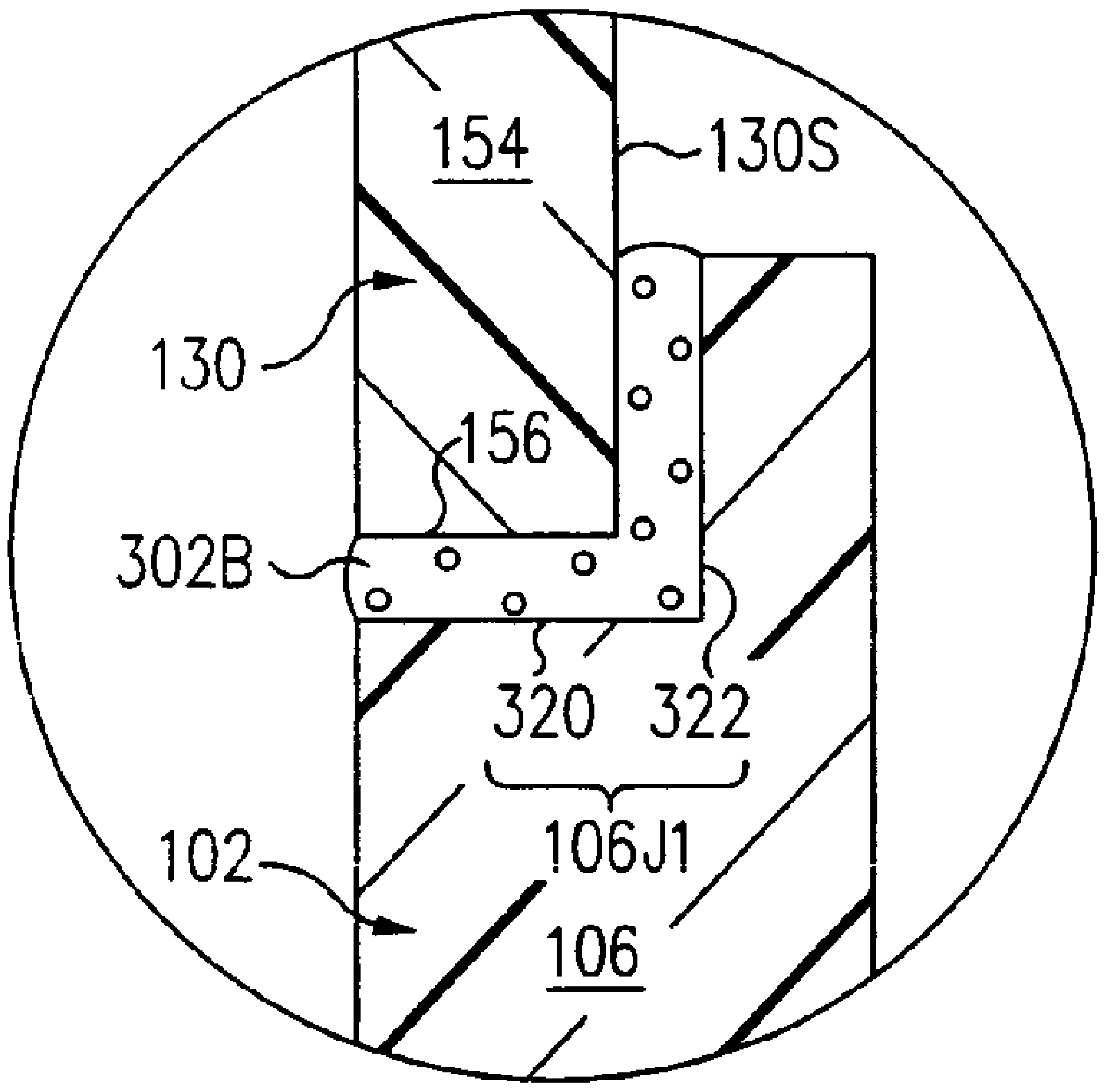
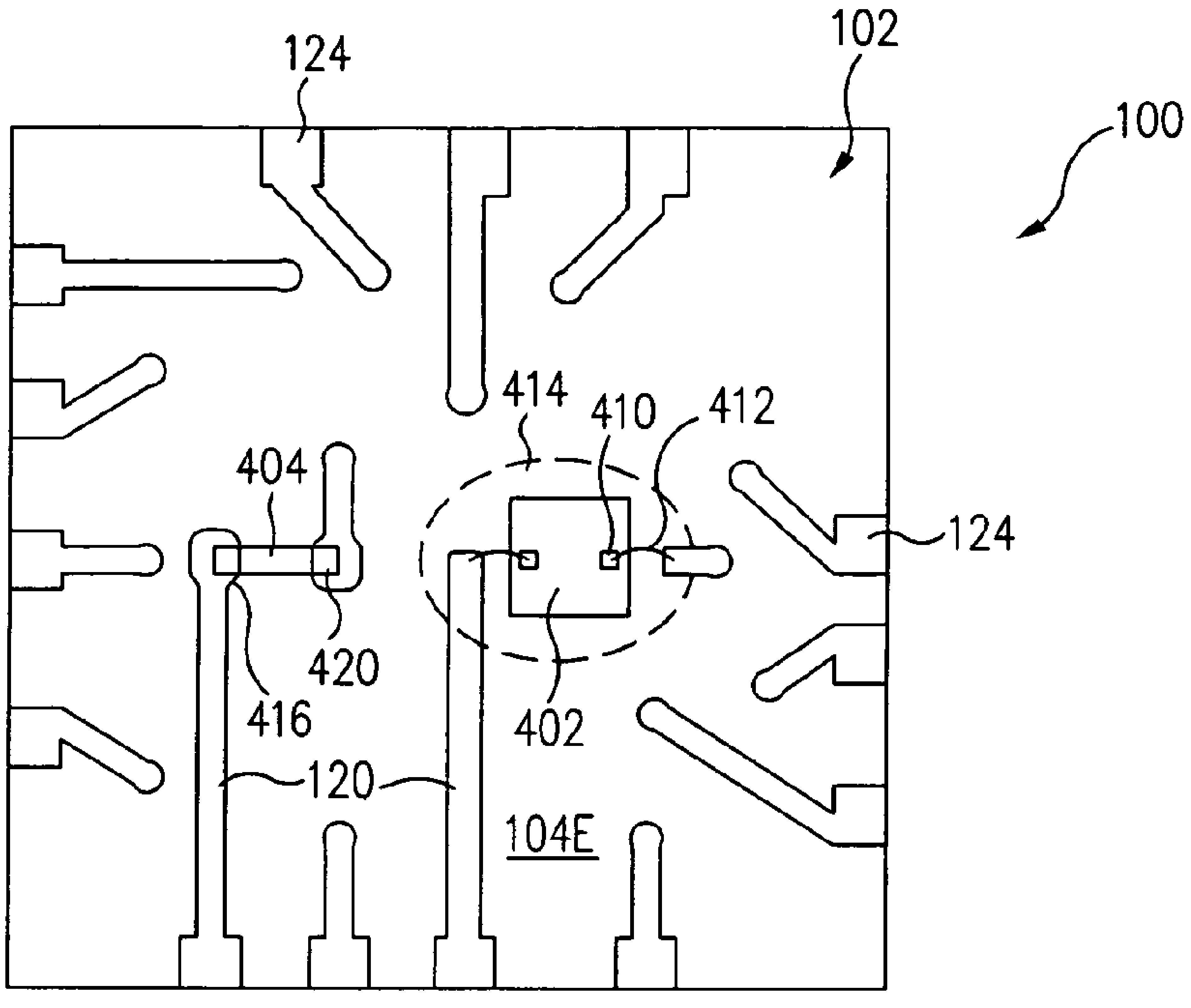


FIG. 3C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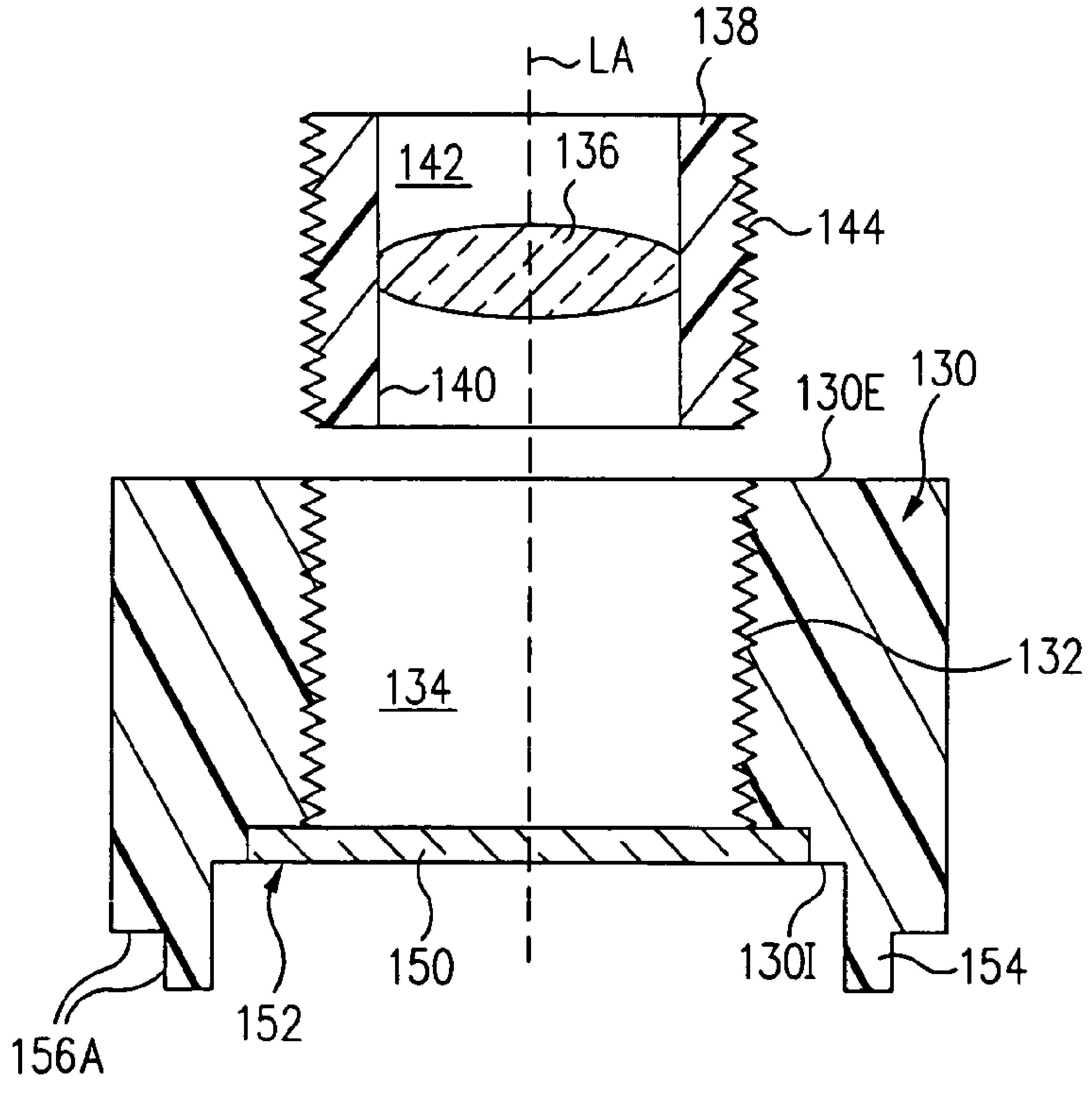
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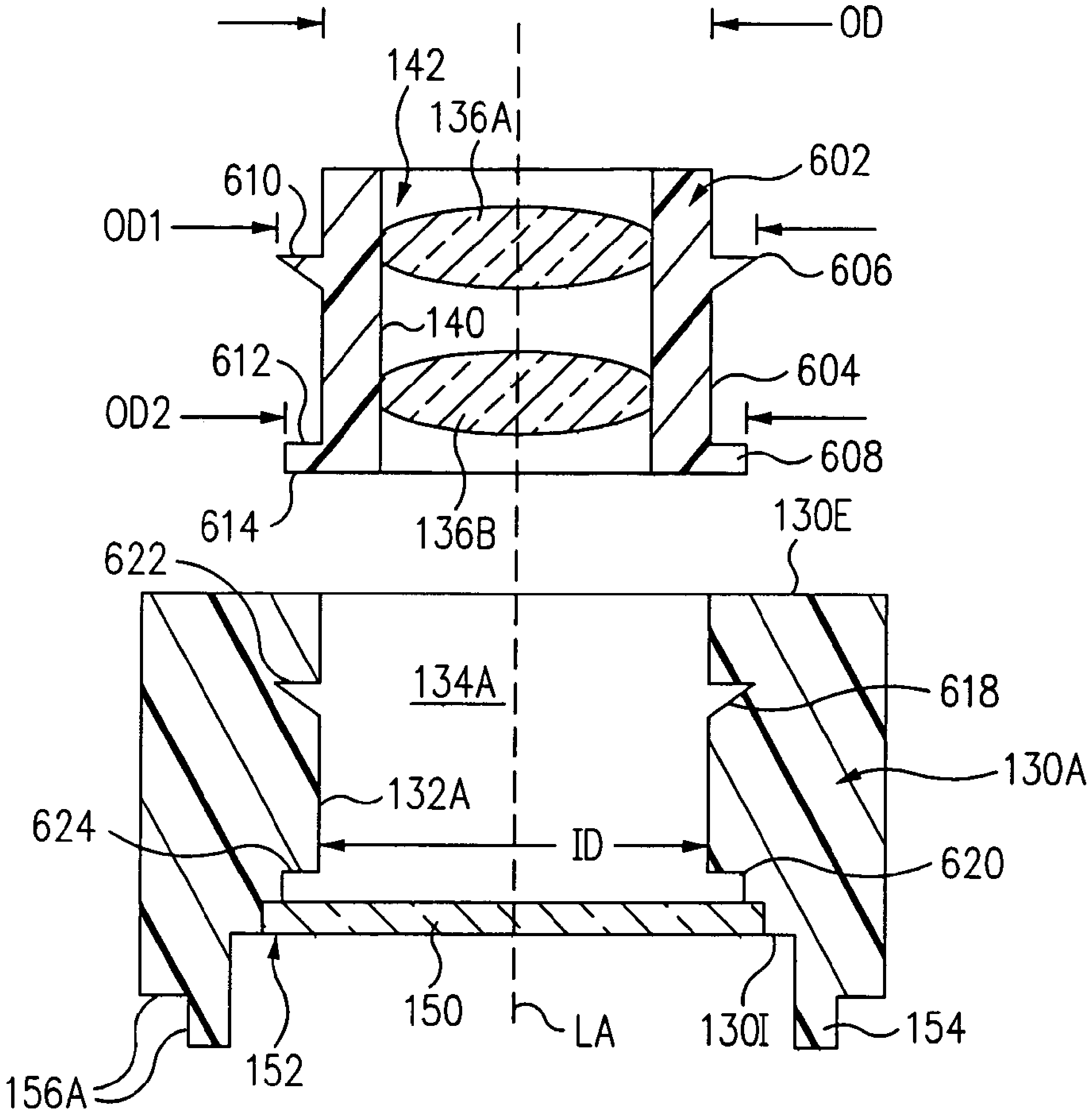
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FIG. 6A

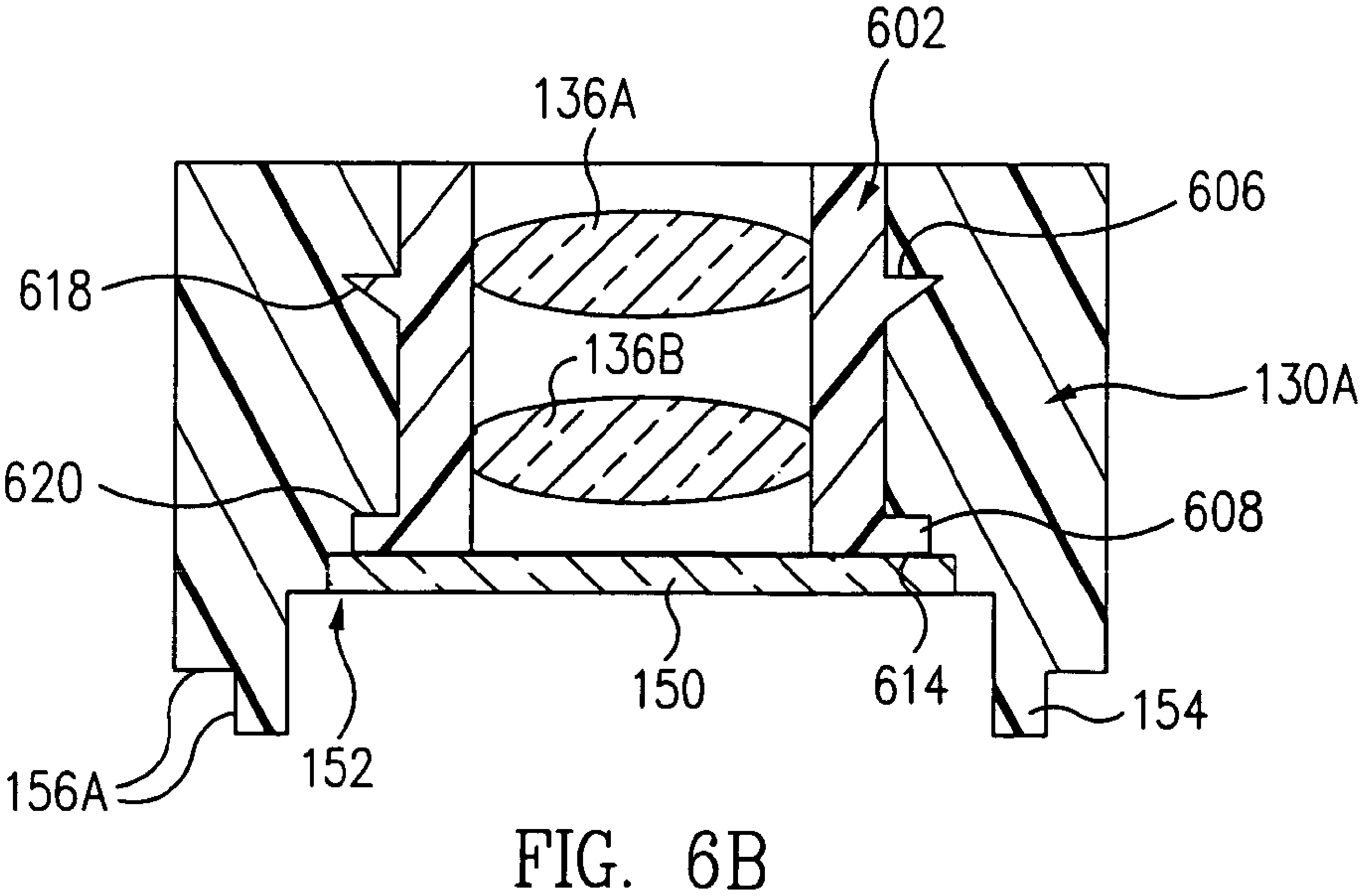
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FIG. 6B

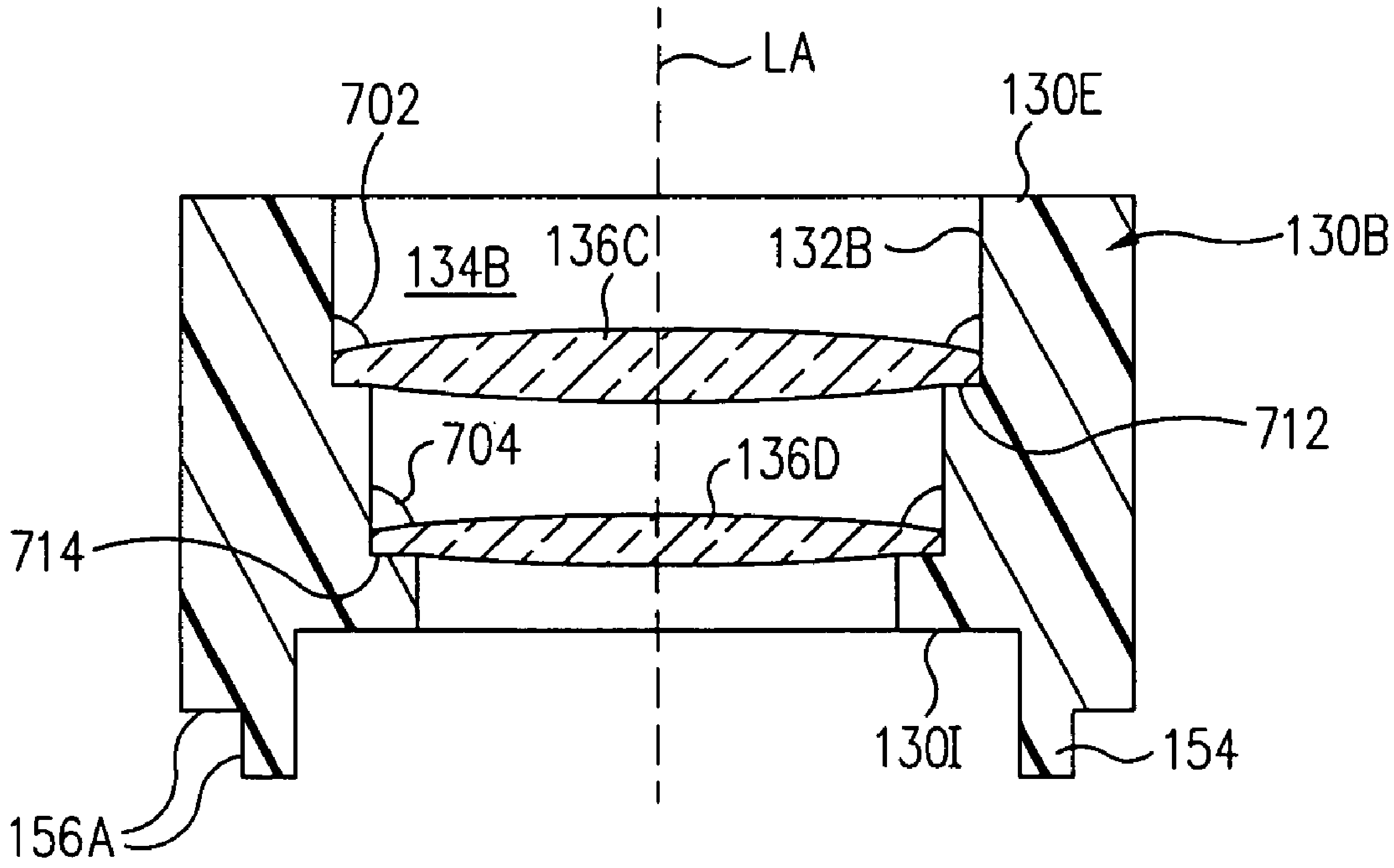
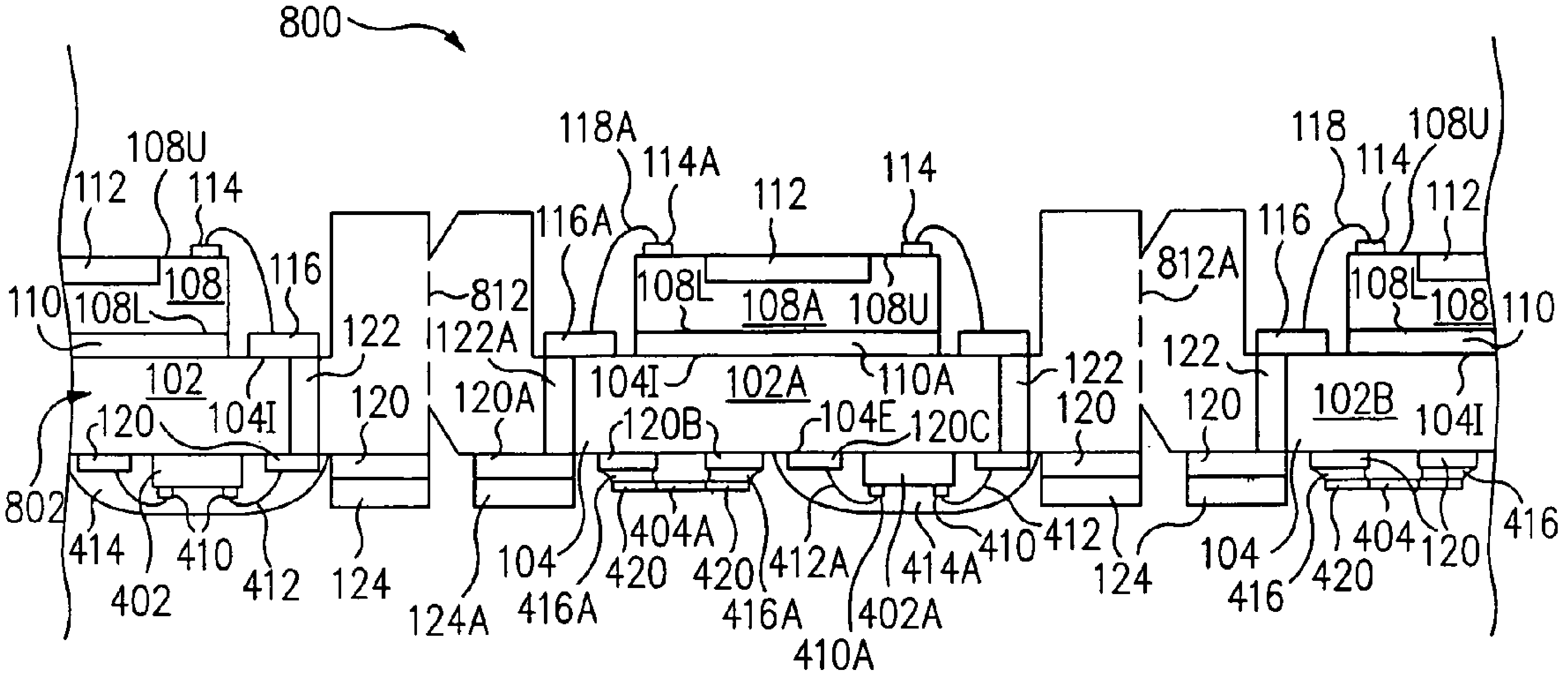


FIG. 7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116A
108L
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108U
104I
102A
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812A
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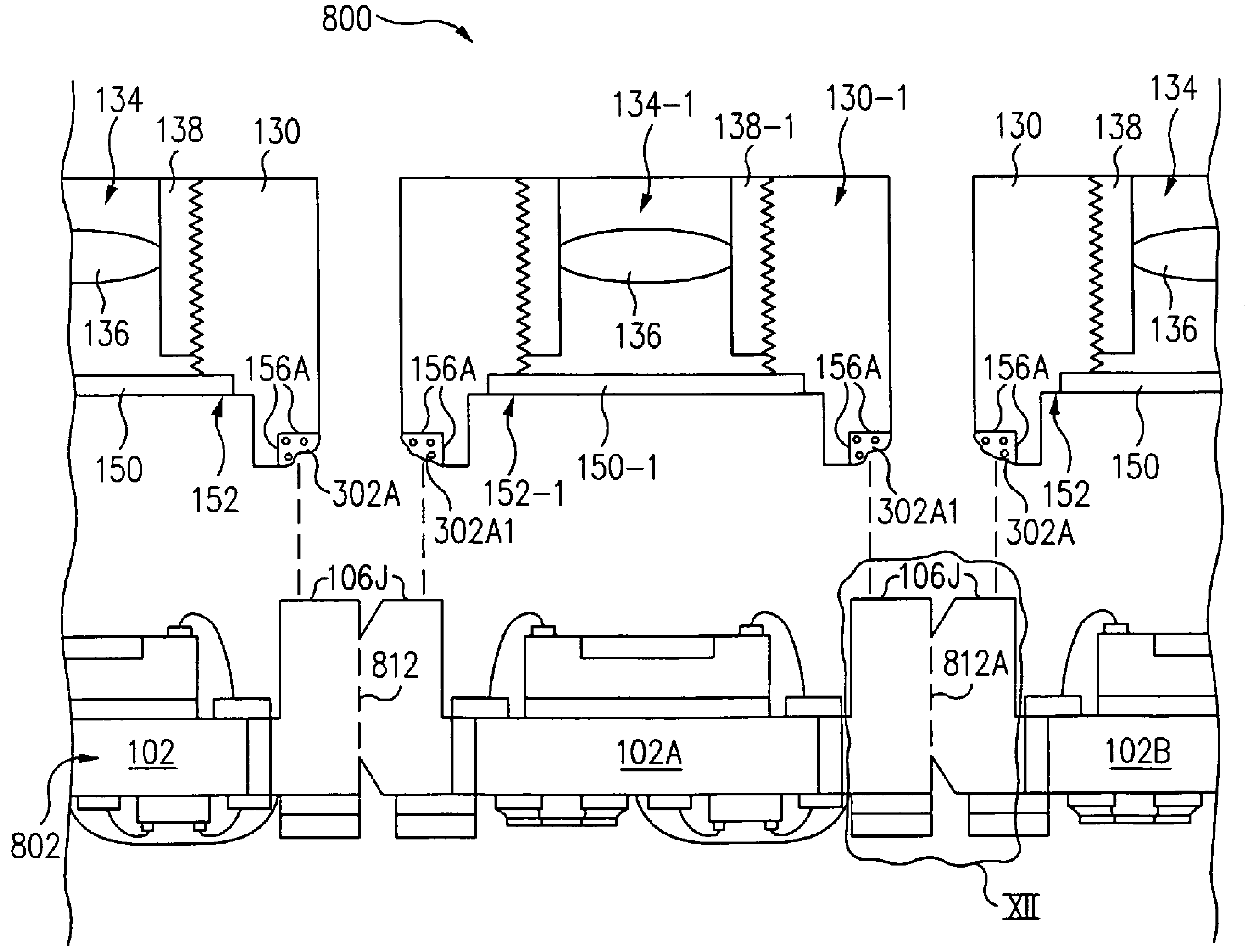
FIG. 8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302A
150-1
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812A
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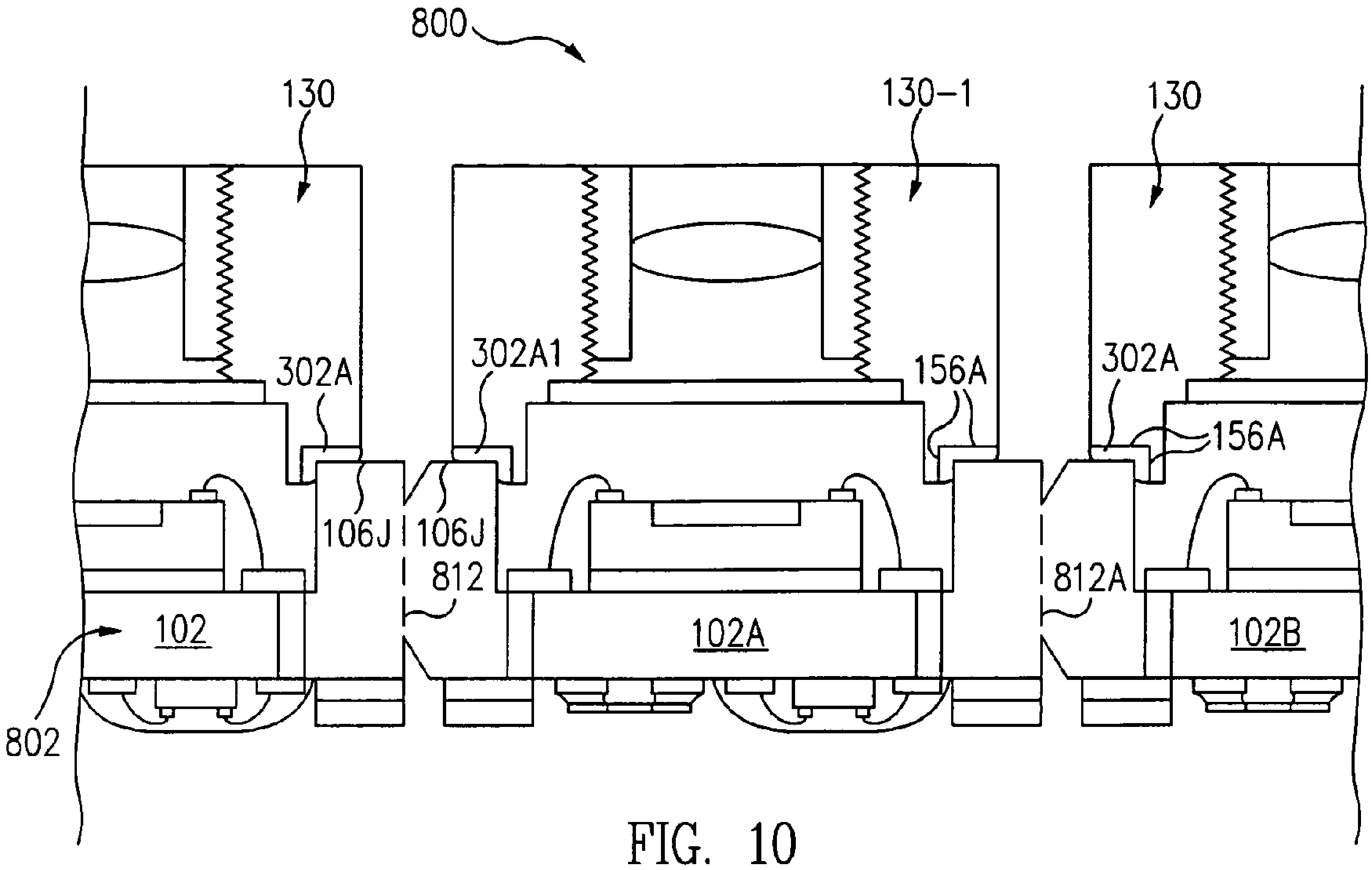
102B
802
XII

FIG. 9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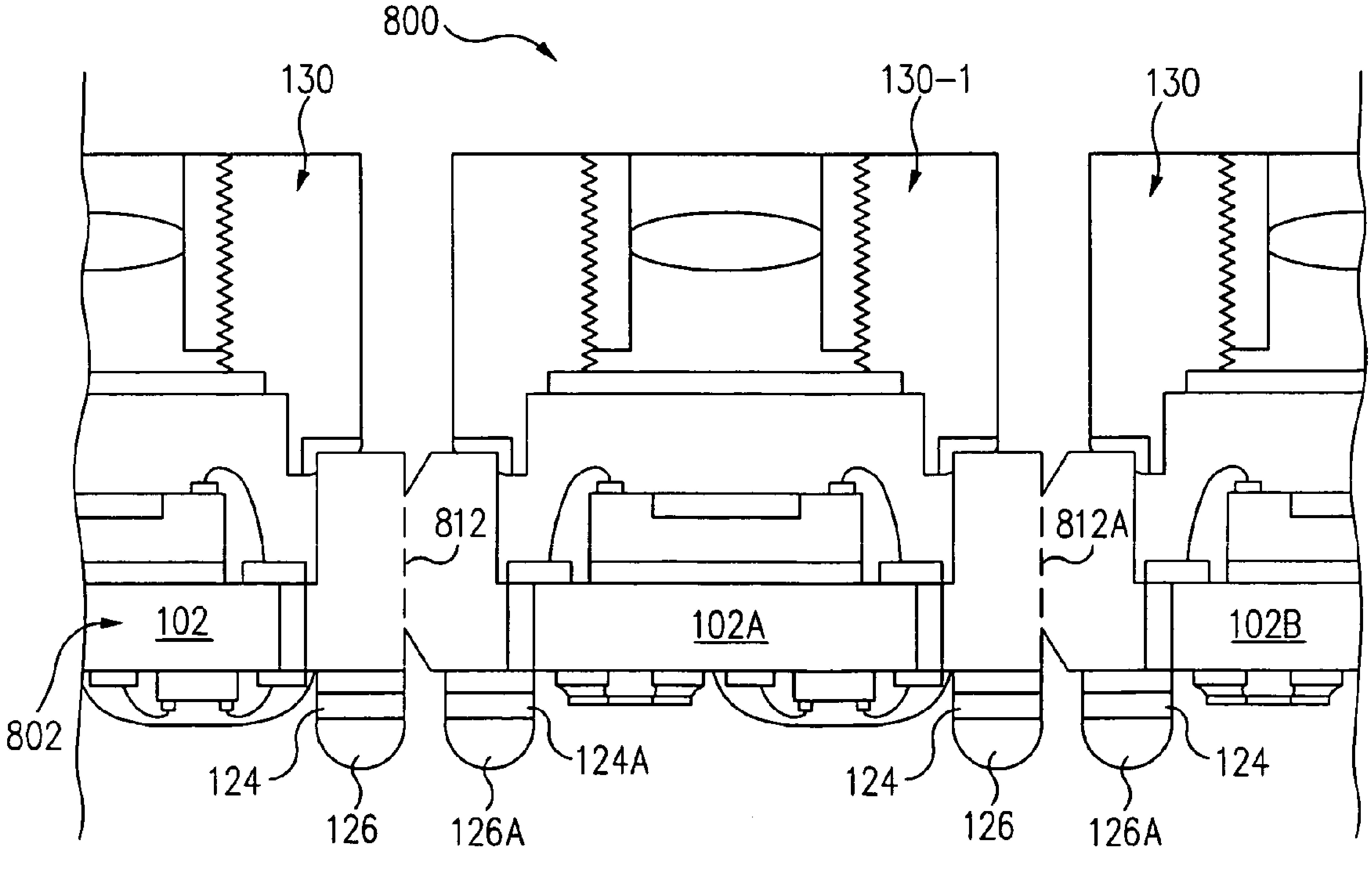
802

FIG. 10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126A
124

FIG. 11

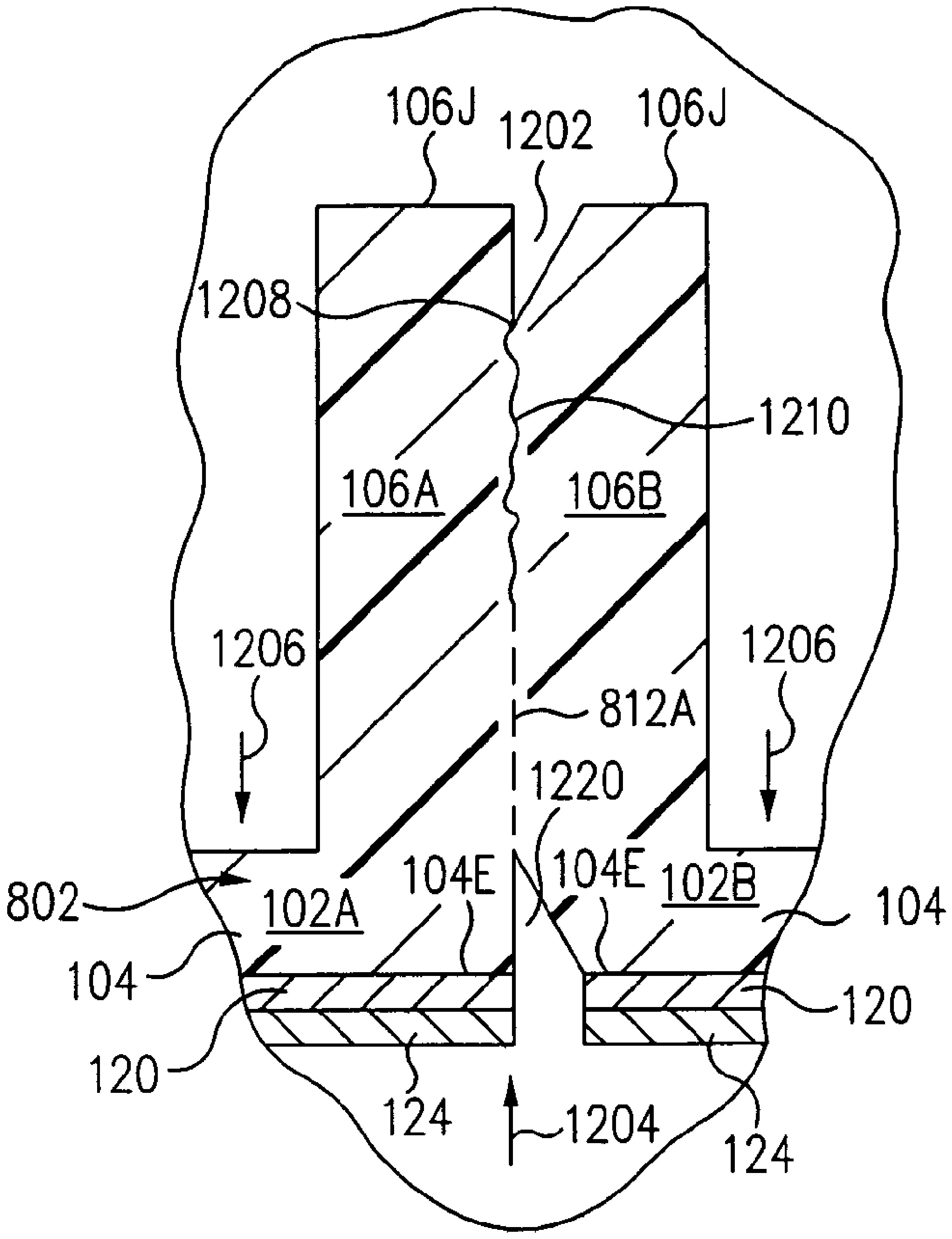

FIG. 12A

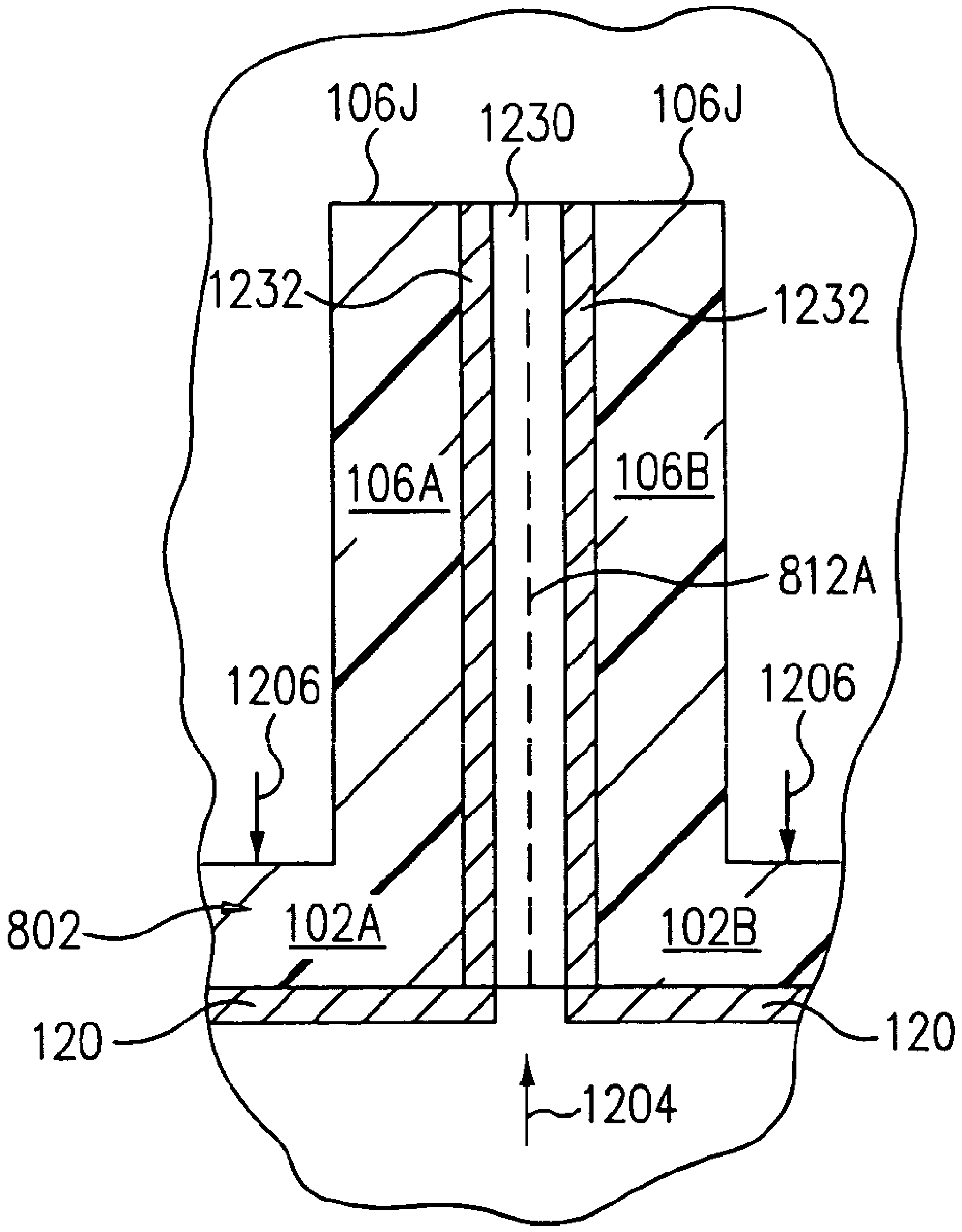

FIG. 12B

OPTICAL MODULE HAVING CAVITY SUBSTRATE

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation of U.S. patent application Ser. No. 09/764,196, filed on Jan. 16, 2001, now U.S. Pat. No. 7,059,040 entitled "Optical Module with Lens Integral Holder Fabrication Method", which is incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to the packaging of electronic components. More particularly, the present invention relates to a method for fabricating an optical module.

2. Description of the Related Art

Image sensors are well known to those of skill in the art. An image sensor included an active area, which was responsive to electromagnetic radiation. The image sensor was used to fabricate an image sensor assembly.

In one prior art image sensor assembly, the image sensor was located within a housing, which supported a window. Radiation passed through the window and struck the active area of the image sensor, which responded to the radiation.

To form the image sensor assembly, the image sensor was mounted to a printed circuit mother board. After the image sensor was mounted, a housing was mounted around the image sensor and to the printed circuit mother board. This housing provided a seal around the image sensor, while at the same time, supported a window above the image sensor.

As the art moves to smaller and lighter weight electronic devices, it becomes increasingly important that the size of the image sensor assembly used within these electronic devices is small. The conventional image sensor assembly described above required a housing to support the window and to seal the image sensor. However, this housing was relatively bulky and, as a result, the image sensor assembly was relatively large.

SUMMARY OF THE INVENTION

In accordance with the present invention, an optical module includes a substrate having a base and a sidewall. The optical module further includes an image sensor coupled to the base and a lens housing coupled to the sidewall.

The sidewall includes a joint surface and the lens housing includes a mounting surface. The mounting surface of the lens housing is coupled to the joint surface of the substrate thus coupling the lens housing to the sidewall.

In one embodiment, the mounting surface and the joint surface are planar and are bonded together with adhesive as a butt bond. The mounting surface has a width sufficient to provide a desired level of protection, e.g., a hermetic seal, of the image sensor from the ambient environment. However, it is desirable to form the mounting surface with a minimal width to minimize the overall width of the optical module.

To minimize the overall width of the optical module, in an alternative embodiment, the mounting surface of the lens housing is formed with a locking feature. The locking feature includes a horizontal surface parallel to the joint surface of the substrate and a vertical surface perpendicular to the joint surface and extending downwards from the horizontal surface. The horizontal surface is bonded to the joint surface and the vertical surface is bonded to an interior surface of the sidewall.

Advantageously, to enter into optical module **100**, dust and moisture is forced to travel horizontally along the interface distance of the horizontal surface and, in addition, is forced to travel vertically along the interface distance of the vertical surface. By forming a relatively long and tortuous interface between the lens housing and the substrate, the environmental protection of the optical module is enhanced. Further, by forming part of this interface in the vertical direction, this enhanced environmental protection is obtained without a corresponding increase in width of the optical module.

As a further advantage, by bonding the vertical surface of the mounting surface of the lens housing to the interior surface of the sidewall of the substrate, the strength of the bond between the lens housing and the substrate is greatly increased compared to the strength of a butt bond. By increasing the strength of the bond between the lens housing and the substrate, the reliability of the optical module is insured.

In an alternative embodiment, the joint surface is formed with a locking feature similar to that described above for the mounting surface. Forming the joint surface as a locking feature enhances the environmental protection as well as reliability of the optical module while at the same time minimizes the overall width of the optical module.

Also in accordance with the present invention, a method of forming an optical module includes coupling an image sensor to a base of a substrate. A lens housing is coupled to a sidewall of the substrate.

To couple the lens housing, a mounting surface of the lens housing is aligned with a joint surface of the substrate. The mounting surface of the lens housing is bonded to the joint surface of the sidewall thus mounting the lens housing to the substrate. In one embodiment, the mounting surface is bonded to the joint surface by a butt bond.

In an alternative embodiment, the mounting surface includes a locking feature. A horizontal surface of the mounting surface is bonded to the joint surface and a vertical surface of the mounting surface is bonded to an interior surface of the sidewall.

In yet another alternative embodiment, the joint surface includes a locking feature. A horizontal surface of the joint surface is bonded to the mounting surface of the lens housing and a vertical surface of the joint surface is bonded to an exterior side surface of the lens housing.

By forming either the mounting surface or the joint surface as a locking feature, the environmental protection as well as reliability of the optical module is enhanced while at the same time the overall width of the optical module is minimized.

To minimize the cost associated with fabricating the optical module, in one embodiment, a plurality of optical modules are fabricated simultaneously in an array from an image sensor substrate comprising a plurality of substrates integrally connected together. Advantageously, the optical modules are tested for validity while still in an array, which is less labor intensive and thus lower cost than testing each optical module on an individual basis. The image sensor substrate is then singulated, e.g., by mechanical snapping, thus forming a plurality of optical modules.

These and other features and advantages of the present invention will be more readily apparent from the detailed description set forth below taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a top plan view of an optical module in accordance with one embodiment of the present invention.

FIG. **2** is a cross-sectional view of the optical module taken along the line II-II of FIG. **1**.

FIGS. **3**A, **3**B and **3**C are enlarged cross-sectional views of the region III of FIG. **2** in accordance with various embodiments of the present invention.

FIG. **4** is a bottom plan view of the optical module of FIG. **2** in accordance with one embodiment of the present invention.

FIG. **5** is a cross-sectional view of a lens housing during assembly in accordance with one embodiment of the present invention.

FIG. **6**A is a cross-sectional view of a lens housing during assembly in accordance with another embodiment of the present invention.

FIG. **6**B is a cross-sectional view of the lens housing of FIG. **6**A assembled with a snap barrel lens support.

FIG. **7** is a cross-sectional view of a fixed focus lens housing in accordance with yet another alternative embodiment of the present invention.

FIG. **8** is a cross-sectional view of an assembly during the fabrication of a plurality of optical modules in accordance with one embodiment of the present invention.

FIGS. **9**, **10** and **11** are cross-sectional views of the assembly of FIG. **8** at further stages during fabrication.

FIGS. **12**A, **12**B are enlarged cross-sectional views of the region XII of an image sensor substrate of FIG. **9** during snapping in accordance with various embodiments of the present invention.

In the following description, the same or similar elements are labeled with the same or similar reference numbers.

DETAILED DESCRIPTION

In accordance with the present invention, an optical module **100** (FIG. **2**) includes a substrate **102** having a base **104** and a sidewall **106**. Optical module **100** further includes an image sensor **108** mounted to base **104** and a lens housing **130** mounted to sidewall **106**.

Sidewall **106** includes a joint surface **106**J and lens housing **130** includes a mounting surface **156**A. Mounting surface **156**A of lens housing **130** is bonded to joint surface **106**J of substrate **102** thus mounting lens housing **130** to sidewall **106**.

To minimize the overall width of optical module **100**, in one embodiment (FIG. **3**B), mounting surface **156**A of lens housing **130** is formed with a locking feature. The locking feature includes a horizontal surface **310** parallel to joint surface **106**J of substrate **102** and a vertical surface **312** perpendicular to joint surface **106**J and extending downwards from horizontal surface **310**. Horizontal surface **310** is bonded to joint surface **106**J and vertical surface **312** is bonded to an interior surface **106**I of sidewall **106** with adhesive **302**A.

Advantageously, to enter into optical module **100**, dust and moisture is forced to travel horizontally along the interface distance of horizontal surface **310** and, in addition, is forced to travel vertically along the interface distance of vertical surface **312**. By forming a relatively long and tortuous interface between lens housing **130** and substrate **102**, the environmental protection of optical module **100** is enhanced. Further, by forming part of this interface in the vertical direction, this enhanced environmental protection is obtained without a corresponding increase in width of optical module **100**.

As a further advantage, by bonding vertical surface **312** to interior surface **106I**, the strength of the bond between lens housing **130** and substrate **102** is greatly increased compared to the strength of a butt bond such as that illustrated in FIG. **3**A. By increasing the strength of the bond between lens housing **130** and substrate **102**, the reliability of optical module **100** is insured.

More particularly, FIG. **1** is a top plan view of an optical module **100** in accordance with one embodiment of the present invention. FIG. **2** is a cross-sectional view of optical module **100** taken along the line II-II of FIG. **1**. Optical module **100** is used in a wide variety of applications, e.g., cameras and cellular telephones.

Referring to FIGS. **1** and **2** together, optical module **100** includes a substrate **102**, e.g., formed of ceramic, pre-molded plastic or laminate. Substrate **102** is a rectangular cup shape enclosure and includes a base **104** and a sidewall **106**. Sidewall **106** is formed around a periphery of base **104** and extended upwards, e.g., in a first direction, from base **104**. In this embodiment, base **104** and sidewall **106** are integral, i.e., are a single piece and not a plurality of separate pieces connected together.

Base **104** includes an interior, e.g., first, surface **104**I and an exterior, e.g., second, surface **104**E. Mounted, sometimes called die attached, to interior surface **104**I is an image sensor **108**. More particularly, a lower, e.g., first, surface **108**L of image sensor **108** is mounted to interior surface **104**I, for example, with adhesive **110**. Image sensor **108** further includes an upper, e.g., second, surface **108**U. An active area **112** and bond pads **114** of image sensor **108** are formed on upper surface **108**U. In this embodiment, interior surface **104**I, lower surface **108**L, and upper surface **108**U are parallel to one another.

In one embodiment, substrate **102** is laminate, e.g., printed circuit board material. To avoid particulate contamination of active area **112** from substrate **102** in accordance with this embodiment, substrate **102** is treated to remove particulates and/or to bind the particulates to substrate **102**. Illustratively, substrate **102** is washed, blown, e.g., air or snow blown, and/or encapsulated with an epoxy coating. Alternatively, or in addition, active area **112** is protected. For example, a window is attached directly over active area **112** and to upper surface **108**U of image sensor **108** using a method similar to that described in Webster et al., U.S. patent application Ser. No. 09/490,717, filed Jan. 25, 2000, now U.S. Pat. No. 6,515,269, issued Feb. 4, 2003; Glenn et al., U.S. patent application Ser. No. 09/577,692, filed May 22, 2000, now U.S. Pat. No. 6,492,699, issued Dec. 10, 2002; and Glenn et al., U.S. patent application Ser. No. 09/610,314, filed Jul. 5, 2000, now U.S. Pat. No. 6,407,381, issued Jun. 18, 2002, which are all herein incorporated by reference in their entireties.

Generally, active area **112** of image sensor **108** is responsive to radiation, e.g., electromagnetic radiation, as is well known to those of skill in the art. For example, active area **112** is responsive to infrared radiation, ultraviolet light, and/or visible light. Illustratively, image sensor **108** is a CMOS image sensor device, a charge coupled device (CCD), a pyroelectric ceramic on CMOS device, or an erasable programmable read-only memory device (EPROM) although other image sensors are used in other embodiments.

Formed on interior surface **104**I of substrate **102** are a plurality of electrically conductive interior traces **116**, which include a first interior trace **116**A. Interior traces **116** are electrically connected to bond pads **114** by bond wires **118**. To illustrate, a first bond pad **114**A of the plurality of bond pads **114** is electrically connected to interior trace **116**A by a first bond wire **118**A of the plurality of bond wires **118**.

Formed on exterior surface **104**E of substrate **102** are a plurality of electrically conductive exterior traces **120**, which include a first exterior trace **120**A. Extending through base **104** from exterior surface **104**E to interior surface **104**I are a plurality of electrically conductive vias **122**, which include a first via **122**A. Exterior traces **120** are electrically connected to interior traces **116** by vias **122**. To illustrate, exterior trace **120**A is electrically connected to interior trace **116**A by via **122**A.

Formed on exterior traces **120** are electrically conductive pads **124**, which include a first pad **124**A. Formed on pads **124** are electrically conductive interconnection balls **126**, e.g., solder. To illustrate, pad **124**A is formed on exterior trace **120**A. A first interconnection ball **126**A of the plurality of interconnection balls **126** is formed on pad **124**A. Interconnection balls **126** are used to connect optical module **100** to a larger substrate **170** such as a printed circuit mother board.

As set forth above, an electrically conductive pathway between bond pad **114**A and interconnection ball **126**A is formed by bond wire **118**A, interior trace **116**A, via **122**A, exterior trace **120**A, and pad **124**A. The other bond pads **114**, bond wires **118**, interior traces **116**, vias **122**, exterior traces **120**, pads **124** and interconnection balls **126** are electrically connected to one another in a similar fashion so are not discussed further to avoid detracting from the principals of the invention.

Although a particular electrically conductive pathway between bond pad **114**A and interconnection ball **126**A is described above, other electrically conductive pathways can be formed. For example, contact metallizations can be formed between the various electrical conductors, e.g., between bond pads **114** and bond wires **118**, between bond wires **118** and interior traces **116**, between exterior traces **120** and pads **124**, and/or between pads **124** and interconnection balls **126**. Alternatively, pads **124** are not formed and interconnection balls **126** are formed directly on exterior traces **120**.

As yet another alternative, interconnection balls **126** are distributed in an array format to form a ball grid array (BGA) type optical module. Alternatively, interconnection balls **126** are not formed, e.g., to form a metal land grid array (LGA) type optical module. Typically, with either a BGA or LGA type optical module, optical module **100** is mounted to larger substrate **170**, which is parallel to upper surface **108**U of image sensor **108**.

In yet another alternative, exterior traces **120** extended upwards on an exterior surface **106**E of sidewall **106** as indicated by the dashed lines and pads **124**/interconnection balls **126** are not formed, e.g., to form a leadless chip carrier (LCC) type optical module. For example, with an LCC type optical module, optical module **100** is mounted with a 900 orientation to a larger substrate **180** such as a printed circuit mother board, which is perpendicular to upper surface **108**U of image sensor **108**. BGA, LGA and LCC type modules are well known to those of skill in the art.

In another embodiment, a flex connector, sometimes called an edge connector or flex strip, is electrically connected to exterior traces **120**, e.g., for applications were optical module **100** is remote from the larger substrate. Other electrically conductive pathway modifications will be obvious to those of skill in the art.

Sidewall **106** of substrate **102** further includes an interior surface **106**I. In this embodiment, interior surface **106**I is parallel to exterior surface **106**E. Further, interior surface **106**I and exterior surface **106**E are perpendicular to interior surface **104**I and exterior surface **104**E, which are parallel to one another. Although various structures may be described as being parallel or perpendicular, it is understood that the structures may not be exactly parallel or perpendicular but only substantially parallel or perpendicular to within accepted manufacturing tolerances.

Extending between exterior surface **106**E and interior surface **106**I of sidewall **106** is a joint surface **106**J. A lens housing **130** is mounted to joint surface **106**J and generally to sidewall **106** of substrate **102**. Illustratively, lens housing **130** is molded plastic such as glass filled NORYL, e.g., glass filled nylon 6/6, although other materials are used in other embodiments. For example, in one embodiment, lens housing **130** is a high temperature plastic such that lens housing **130** maintains integrity during reflow, e.g., during melting of interconnection balls **126**. In another embodiment, lens housing **130** is a low temperature plastic, for example, when there is no reflow, e.g., when interconnection balls **126** are not formed.

Lens housing **130** includes an interior cylindrical surface **132**, which defines a central aperture **134** having a longitudinal axis LA perpendicular to upper surface **108**U of image sensor **108**. Central aperture **134** extends upwards and is aligned above active area **112** such that active area **112** is visible through central aperture **134** as best shown in FIG. **1**.

To facilitate attachment of an optical element **136** such as a lens (hereinafter lens **136**), interior cylindrical surfaced **132** is threaded. Stated another way, central aperture **134** is a female threaded aperture.

Lens **136** is mounted in a support **138**, hereinafter referred to as lens support **138**. In this embodiment, lens support **138** is a cylindrical annulus having an interior cylindrical surface **140**, which defines an aperture **142**. Lens **136** is positioned in aperture **142** such that lens **136** and lens support **138** also have longitudinal axis LA. Interior cylindrical surface **140** may not be exactly cylindrical, e.g., is hourglass shaped, but has other shapes in other embodiments.

Lens support **138** has an exterior cylindrical surface **144**, which is threaded. Stated another way, lens support **138** is male threaded. Of importance, the threading of exterior cylindrical surface **144** corresponds with the threading of interior cylindrical surface **132** allowing threaded attachment of lens support **138** to lens housing **130**.

Lens support **138** is threaded into central aperture **134** so that exterior cylindrical surface **144** is threadedly attached to interior cylindrical surface **132** of lens housing **130**.

Advantageously, lens **136** is readily adjusted relative to image sensor **108** by rotating lens support **138**. More particularly, lens support **138** is rotated around longitudinal axis LA in a first direction, e.g., clockwise looking downward at lens support **138**, to move lens support **138** and lens **136** towards image sensor **108**. Conversely, lens support **138** is rotated around longitudinal axis LA in a second direction opposite the first direction, e.g., counterclockwise looking downward at lens support **138**, to move lens support **138** and lens **136** away from image sensor **108**.

During rotation of lens support **138**, a possibility exists that particulates may be generated, e.g., due to friction between lens support **138** and lens housing **130**. To prevent these particulates from falling on and contaminating active area **112**, a window **150** is mounted to lens housing **130** downwards, e.g., in a second direction, and below central aperture **134**.

In this embodiment, central aperture **134** extends from an interior, e.g., first, surface **130**I of lens housing **130** to an exterior, e.g., second, surface **130**E of lens housing **130**. Interior surface **130**I includes a pocket **152** corresponding in size to window **150**. Window **150** is mounted into pocket **152** and, more generally, to lens housing **130**, for example, with adhesive.

During use, radiation is directed at optical module **100**. This radiation passes through lens **136** and window **150** and strikes active area **112**, which responds to the radiation as is well known to those of skill in the art. In this embodiment, lens support **138** is rotated as described above until radiation passing through lens **136** is properly focused on active area **112** of image sensor **108**. Once proper focus is attained, lens support **138** is prevented from unintentional rotation. For example, adhesive is applied to secure lens support **138** to lens housing **130**.

In an alternative embodiment, active area **112** of image sensor **108** transmits radiation such as electromagnetic radiation. For example, image sensor **108** is a light emitting diode (LED) micro-display. In accordance with this embodiment, radiation transmitted by active area **112** passes through window **150**, through lens **136** and emanates from optical module **100**. For simplicity, in the above and following discussions, active area **112** as a receiver of radiation is set forth. However, in light of this disclosure, those of skill in the art will recognize that generally active area **112** can be a receiver of radiation, a transmitter of radiation, or a transceiver, i.e., a transmitter and a receiver, of radiation.

In this embodiment, lens housing **130** is cap shaped. More particularly, extending downwards from interior surface **130**I of lens housing **130** is a mounting rim **154** having a mounting surface **156**A as described in greater detail below with reference to FIGS. **3**A, **3**B and **3**C. However, in an alternative embodiment, lens housing **130** is formed without a mounting rim **154** and interior surface **130**I includes mounting surface **156**A, i.e., mounting surface **156**A is the periphery of interior surface **130**I.

Referring again to the embodiment illustrated in FIG. **2**, mounting surface **156**A is bonded, sometimes called mounted or attached, to joint surface **106**J of substrate **102**. In this manner, lens housing **130** is mounted to substrate **102**.

FIG. **3**A is an enlarged cross-sectional view of the region III of FIG. **2** in accordance with one embodiment of the present invention. Referring now to FIGS. **2** and **3**A together, mounting surface **156** of lens housing **130** is planar. Similarly, joint surface **106**J of substrate **102** is also planar. Adhesive **302** between mounting surface **156** and joint surface **106**J bonds mounting surface **156** to joint surface **106**J. Such a bond between planar surfaces is typically referred to as a butt bond.

Further, adhesive **302** forms a seal between lens housing **130** and substrate **102**, which protects image sensor **108** from environmental degradation, e.g., from dust and moisture. More particularly, substrate **102**, lens housing **130** and adhesive **302** form an enclosure around image sensor **108** and protect image sensor **108** from the ambient environment.

Mounting surface **156** has a width **W1** sufficient to provide a desired level of protection, e.g., a hermetic seal, of image sensor **108** from the ambient environment, e.g., from dust and moisture (hereinafter referred to as environmental protection). Generally, to maximize environmental protection of image sensor **108**, width **W1** should also be maximized to increase the distance, sometimes called the interface distance, over which dust and moisture must travel at the interface of mounting surface **156** and joint surface **106**J to enter into optical module **100**. In one embodiment, width **W1** is 0.75 mm to 1.0 mm. However, maximizing width **W1** correspondingly increases the overall width of optical module **100** yet it is desirable to minimize the overall width of optical module **100**.

FIG. **3**B is an enlarged cross-sectional view of the region III of FIG. **2** in accordance with an alternative embodiment of the present invention. Referring now to FIGS. **2** and **3**B together, in accordance with this embodiment, mounting surface **156**A is a locking feature. More particularly, mounting surface **156**A is a step like locking feature having a horizontal, e.g., first, surface **310** parallel to joint surface **106**J and a vertical, e.g., second, surface **312** perpendicular to joint surface **106**J and extending downwards from horizontal surface **310**.

Adhesive **302**A is between horizontal surface **310** and joint surface **106**J and is also between vertical surface **312** and interior surface **106**I of sidewall **106**. Accordingly, to enter into optical module **100**, dust and moisture is forced to travel horizontally along the interface distance of horizontal surface **310** and, in addition, is forced to travel vertically along the interface distance of vertical surface **312**. By forming a relatively long and tortuous interface between lens housing **130** and substrate **102**, the environmental protection of optical module **100** is enhanced. Further, by forming part of the interface between lens housing **130** and substrate **102** in the vertical direction, i.e., between vertical surface **312** and interior surface **106**I of sidewall **106**, this enhanced environmental protection is obtained without a corresponding increase in width of optical module **100**. For example, a width **W2** of the combination of mounting rim **154** and sidewall **106** is 0.5 mm or less.

Adhesive **302**A forms a bond between horizontal surface **310** and joint surface **106**J. In addition, adhesive **302**A forms a bond between vertical surface **312** and interior surface **106**I of sidewall **106**. Advantageously, by bonding vertical surface **312** to interior surface **106**I, the strength of the bond between lens housing **130** and substrate **102** is greatly increased compared to the strength of a butt bond such as that illustrated in FIG. **3**A. By increasing the strength of the bond between lens housing **130** and substrate **102**, the reliability of optical module **100** is insured.

FIG. **3**C is an enlarged cross-sectional view of the region III of FIG. **2** in accordance with another alternative embodiment of the present invention. Referring now to FIGS. **2** and **3**C, in accordance with this embodiment, joint surface **106**J**1** is a locking feature. More particularly, joint surface **106**J**1** is a step like locking feature having a horizontal, e.g., first, surface **320** parallel to mounting surface **156** and a vertical, e.g., second, surface **322** perpendicular to mounting surface **156** and extending upwards from horizontal surface **320**.

Adhesive **302**B is between horizontal surface **320** and mounting surface **156** and is also between vertical surface **322** and an exterior side surface **130**S of lens housing **130**. For reasons similar to those discussed above in regards to FIG. **3**B, forming joint surface **106**J**1** as a locking feature enhances the environmental protection as well as reliability of optical module **100** while at the same time minimizes the overall width of optical module **100**.

FIG. **4** is a bottom plan view of optical module **100** of FIG. **2** in accordance with one embodiment of the present invention. Referring now to FIGS. **2** and **4**, in accordance with this embodiment, one or more electronic components **402**, **404** are mounted to exterior surface **104**E of base **104** of substrate **102**. Electronic components **402**, **404** are sometimes referred to as surface mounted components.

Illustratively, electronic component **402** is an active component such as an integrated circuit, e.g., an ASIC such as a controller chip for image sensor **108**. As a further illustration, electronic component **404** is a passive component such as a resistor, capacitor, or inductor. Electronic components **402**, **404** are hereinafter referred to as active component **402** and passive component **404**, respectively. Generally, an active component actively changes an electronic signal whereas a passive component simply has an interaction with an electronic signal.

Although a single active component **402** and a single passive component **404** are illustrated in FIGS. **2** and **4**, optical module **100** includes more than one active component **402** and/or more than one passive component **404** in alternative embodiments. In other alternative embodiments, optical module **100** does not contain any active components **402**, does not contain any passive components **404**, or does not contain any active components **402** or passive components **404**.

In FIG. **4**, exterior traces **120** are illustrated for purposes of clarity. However, exterior traces **120** are typically covered with a dielectric protective layer as those of skill in the art will understand. Further, interconnection balls **126** are not illustrated also for purposes of clarity.

Referring still to FIGS. **2** and **4** together, active component **402** is mounted to exterior surface **104**E of base **104**, e.g., with adhesive. Bond pads **410** of active component **402** are electrically connected to exterior traces **120** by bond wires **412**. Although two bond pads **410** are illustrated in FIG. **4**, those of skill in the art will understand that the number of bond pads **410** depends upon the particular input/output requirements of active component **402**. To protect active component **402** and bond wires **412**, active component **402** and bond wires **412** are sealed in an encapsulant **414**, sometimes called glob top encapsulated.

Passive component **404** is surface mounted to exterior traces **120**, for example, with solder **416**. More particularly, connector ends **420** of passive component **404** are mounted to exterior traces **120** by solder **416**.

Although particular mountings for active component **402** and passive component **404** are illustrated in FIGS. **2** and **4**, and discussed above, in alternative embodiments, active component **402** and/or passive component **404** are mounted using other well known techniques, e.g., flip-chip mounted.

FIG. **5** is a cross-sectional view of lens housing **130** during assembly in accordance with one embodiment of the present invention. As shown in FIG. **5**, window **150** is mounted into pocket **152** of lens housing **130**, e.g., with adhesive. Lens **136** is mounted into lens support **138**, e.g., with adhesive. Although mounting of a single lens **136** is illustrated, in alternative embodiments, more than one lens **136** or other optical elements are mounted into lens support **138**.

Lens support **138** is positioned directly above central aperture **134** such that exterior cylindrical surface **144** of lens support **138** is aligned with interior cylindrical surface **132** of central aperture **134**. Lens support **138** is rotated in a first direction to threadedly attach exterior cylindrical surface **144** to interior cylindrical surface **132** and thus to threadedly attached lens support **138** to lens housing **130** as illustrated in FIG. **2**. Although window **150** is mounted to lens housing **130** before lens support **138**, in an alternative embodiment, lens support **138** is threadedly attached to lens housing **130** before window **150** is mounted to lens housing **130**. In yet another embodiment, window **150** is not used.

FIG. **6**A is a cross-sectional view of a lens housing **130**A during assembly in accordance with another embodiment of the present invention. As shown in FIG. **6**A, window **150** is mounted into pocket **152** of lens housing **130**A, e.g., with adhesive. Lenses **136**A, **136**B are mounted into a snap barrel lens support **602**, e.g., with adhesive. More particularly, lenses **136**A, **136**B are mounted to interior cylindrical surface **140** and in aperture **142** of snap barrel lens support **602**.

In accordance with this embodiment, snap barrel lens support **602** is designed to snap mount into lens housing **130**A. For this reason, exterior surface **604** of snap barrel lens support **602** includes one or more locking features. In this embodiment, exterior surface **604** includes a first locking feature **606** and a second locking feature **608**.

Locking features **606**, **608** are tabs extending outward from exterior surface **604** and away from longitudinal axis LA of snap barrel lens support **602** in a direction perpendicular to longitudinal axis LA. Locking features **606**, **608** are hereinafter referred to as tabs **606**, **608**, respectively.

As shown in FIG. **6**A, tab **606** is triangular in cross-section and includes a lip **610**. Tab **608** is rectangular in cross-section and includes an upper, e.g., first, lip **612** and a lower, e.g., second, lip **614**.

Lens housing **130**A includes an interior cylindrical surface **132**A, which is smooth in this embodiment. However, formed in interior cylindrical surface **132**A are one or more locking features corresponding to the locking features of snap barrel lens support **602**, e.g., corresponding to tabs **606**, **608**. More particularly, interior cylindrical surface **132**A includes a first locking feature **618** and a second locking feature **620** corresponding to tabs **606**, **608**, respectively, of snap barrel lens support **602**.

Locking features **618**, **620** are notches extending outward from interior cylindrical surface **132**A and away from longitudinal axis LA of central aperture **134**A and in a direction perpendicular to longitudinal axis LA. Locking features **618**, **620** are hereinafter referred to as notches **618**, **620**, respectively.

As shown in FIG. **6**A, notch **618** is triangular in cross-section and includes a shelf **622**. Notch **620** is step shaped in cross-section and includes a shelf **624**.

Generally, the inner diameter ID of central aperture **134**A of lens housing **130**A is approximately equal to and slightly greater than the outer diameter OD of exterior surface **604** of snap barrel lens support **602**. However, the maximum outer diameter OD1 of tab **606** is slightly greater than inner diameter ID. Similarly, the maximum outer diameter OD2 of tab **608** is slightly greater than inner diameter ID.

FIG. **6**B is a cross-sectional view of lens housing **130**A of FIG. **6**A assembled with snap barrel lens support **602**. Referring now to FIGS. **6**A and **6**B together, to mount snap barrel lens support **602** to lens housing **130**A, snap barrel lens support **602** is aligned directly above central aperture **134**A as shown in FIG. **6**A.

Snap barrel lens support **602** is moved downwards and pressed into central aperture **134**A. Since outer diameter OD1 and outer diameter OD2 of tabs **606**, **608**, respectively, are greater than inner diameter ID of central aperture **134**A, pressing of snap barrel lens support **602** causes tabs **606**, **608**, to be compressed inwards towards longitudinal axis LA. Tabs **606**, **608** are slid along interior cylindrical surface **132**A to notches **618**, **620**. Upon reaching notches **618**, **620**, tabs **606**, **608** snap outwards and into notches **618**, **620**, respectively, thus mounting snap barrel lens support **602** to lens housing **130**A.

Referring now to FIG. **6**B, once tab **606** snaps into notch **618**, lip **610** (FIG. **6**A) of tab **606** is engaged with shelf **622** (FIG. **6**A) of notch **618**. Similarly, once tab **608** snaps into notch **620**, upper lip **612** (FIG. **6**A) of tab **608** is engaged with shelf **624** (FIG. **6**A) of notch **620** and lower lip **614** is engaged with window **150**. This engagement of lips **610**, **612** with shelves **622**, **624**, respectively, prevents snap barrel lens support **602** from being unintentionally removed from central aperture **134**A. In one embodiment, adhesive is applied to further secure snap barrel lens support **602** to lens housing **130**A.

Once snap barrel lens support **602** is mounted to lens housing **130**A, the position of lenses **136**A, **136**B are fixed. This type of assembly is sometimes referred to as a fixed focus lens assembly. FIG. **7** is a cross-sectional view of a fixed focus lens housing **130**B in accordance with yet another alternative embodiment of the present invention.

Referring now to FIG. **7**, in accordance with this embodiment, lenses **136**C, **136**D are mounted directly in central aperture **134**B of lens housing **130**B. More particularly, lens **136**C, **136**D are mounted to interior cylindrical surface **132**B, for example, with adhesives **702**, **704** such as epoxy. To facilitate positioning and mounting of lenses **136**C, **136**D, in one embodiment, interior cylindrical surface **132**B is formed with shelves **712**, **714** protruding inwards from interior cylindrical surface **132**B towards longitudinal axis LA. Lenses **136**C, **136**D are placed on shelves **712**, **714**, respectively, and adhesives **702**, **704** are applied around the peripheries of lenses **136**C, **136**D and cured, if necessary, thus mounting lenses **136**C, **136**D to lens housing **130**B.

Since lenses **136**C, **136**D are fixed in place, any possibility of particulate generation due to motion of lenses **136**C, **136**D is eliminated. Accordingly, in this embodiment, a window is unnecessary and is not used. However, in an alternative embodiment, a window similar to window **150** of optical module **100** of FIG. **2** is used. In another alternative embodiment, lenses **136**C, **136**D do not have any optical power or properties but are transparent windows. For example, only a single window, e.g., lens **136**C or **136**D, is used. Lens housing **130**B in accordance with this embodiment is sometimes called a cap lid with window.

FIG. **8** is a cross-sectional view of an assembly **800** during the fabrication of a plurality of optical modules **100** in accordance with one embodiment of the present invention. Referring now to FIG. **8**, assembly **800** includes an image sensor substrate **802** comprising a plurality of individual substrates **102** integrally connected together. Each of substrates **102** is delineated by a singulation street **812**, which is located between adjacent substrates **102**. For example, a first singulation street **812**A of a plurality of singulation streets **812** delineates a first substrate **102**A of the plurality of substrates **102** from a second substrate **102**B of the plurality of substrates **102**. The other substrates **102** are similarly delineated from adjacent substrates **102** by corresponding singulation streets **812**.

Substrates **102** include interior traces **116** on interior surfaces **104**I of bases **104** of substrates **102**. Substrates **102** also include vias **122** extending through bases **104** of substrates **102**. Substrates **102** further include exterior traces **120** and pads **124** on exterior surfaces **104**E of bases **104** of substrates **102**.

Passive components **404** are mounted to exterior traces **120** by solders **416** formed between connector ends **420** of passive components **404** and exterior traces **120**. To illustrate, a first passive component **404**A of the plurality of passive components **404** is mounted to exterior traces **120**B of the plurality of exterior traces **120** by solders **416**A of the plurality of solders **416**.

To mount passive component **404**A, in one embodiment, solder paste is applied, e.g., by screening, to exterior traces **120**B. Connector ends **420** of passive component **404**A are placed in contact with the solder paste. Assembly **800** is heated to melt the solder paste and form solders **416**A between connector ends **420** of passive component **404**A and exterior traces **120**B. The other passive components **404** are mounted to exterior traces **120** in a similar manner and, typically, simultaneously.

Active components **402** are mounted to exterior surfaces **104**E of bases **104** of substrates **102**, e.g., with die attach adhesives. To illustrate, a first active component **402**A of the plurality of active components **402** is mounted to exterior surface **104**E of base **104** of substrate **102**A by adhesive such that bond pads **410** are facing outwards and are exposed. The other active components **402** are mounted to substrates **102** in a similar manner.

Bond pads **410** of active components **402** are electrically connected to exterior traces **120** by bond wires **412** formed using a wirebonding tool. To illustrate, active component **402**A includes a first bond pad **410**A of the plurality of bond pads **410**. Bond pad **410**A is electrically connected to an exterior trace **120**C of the plurality of exterior traces **120** by a first bond wire **412**A of the plurality of bond wires **412**. The other bond pads **410** are electrically connected to exterior traces **120** by bond wires **412** in a similar manner.

Active components **402**, bond wires **412** and bond pads **410** are sealed in encapsulants **414**, sometimes called glob top encapsulated. To illustrate, active component **402**A and the corresponding bond wires **412** and bond pads **410** are sealed in a first encapsulant **414**A of the plurality of encapsulant **414**. In one embodiment, to form encapsulant **414**A, an encapsulant is dispensed, e.g., using a needle dispenser, to cover active component **402**A and the corresponding bond wires **412** and bond pads **410**. The encapsulant is cured, if necessary, to form encapsulant **414**A. The other encapsulants **414** are formed in a similar manner.

Although particular techniques for attaching active components **402** and passive components **404** are described above, active components **402** and passive components **404** can be attached to substrates **102** in a variety of different manners. For example, active components **402** can be flip-chip mounted to exterior traces **120**. The particular techniques used to attach active components **402** and passive components **404** are not essential to the invention.

Lower surfaces **108**L of image sensors **108** are attached to interior surfaces **104**I of bases **104** of substrates **102** by adhesives **110**. To illustrate, a lower surface **108**L of a first image sensor **108**A of the plurality of image sensors **108** is attached to interior surface **104**I of base **104** of substrate **102**A by a first adhesive **110**A of the plurality of adhesives **110**. The other image sensors **108** are similarly attached.

Bond pads **114** of image sensors **108** are electrically connected to interior traces **116** by bond wires **118** using a wirebonding tool. To illustrate, image sensor **108**A includes bond pad **114**A on upper surface **108**U of image sensor **108**A. Bond pad **114**A is electrically connected to interior trace **116**A by bond wire **118**A. The other bond pads **114** are electrically connected to the other interior traces **116** by the other bond wires **118** in a similar manner.

FIG. **9** is a cross-sectional view of assembly **800** of FIG. **8** at a further stage during fabrication. Referring now to FIG. **9**, lens housings **130** are assembled. Illustratively, windows **150** are mounted into pockets **152**, e.g., with adhesives, in lens housings **130**. Lens supports **138** are mounted into central apertures **134** of lens housings **130**.

To illustrate, a first lens housing **130-1** of the plurality of lens housings **130** includes a first pocket **152-1** of the plurality of pockets **152**. A first window **150-1** of the plurality windows **150** is mounted into pocket **152-1**. Lens housing **130-1** further includes a first central aperture **134-1** of the plurality of central apertures **134**. A first lens support **138-1** of the plurality of lens supports **138** is threaded into central aperture **134-1**. The other windows **150** and lens supports **138** are mounted to the other lens housings **130** in a similar manner.

Adhesives **302**A are applied to mounting surfaces **156**A of lens housings **130** or, alternatively, to joint surfaces **106**J of substrates **102**. To illustrate, a first adhesive **302A1** of the plurality of adhesives **302**A is applied to mounting surface **156**A of lens housing **130-1**. The other adhesives **302**A are applied in a similar manner.

Lens housings **130** are aligned with substrates **102**, e.g., with a mechanical or optical alignment system. To illustrate, mounting surface **156**A of lens housing **130-1** is aligned with joint surface **106**J of substrate **102**A. The other lens housings **130** are aligned with the other substrates **102** in a similar manner.

FIG. **10** is a cross-sectional view of assembly **800** of FIG. **9** at a further stage during fabrication. Referring now to FIGS. **9** and **10** together, lens housings **130** are mounted to substrates **102**. Generally, lens housings **130** are moved downwards such that adhesives **302**A are squeezed between substrates **102** and lens housings **130**. Adhesives **302**A are cured, if necessary, thus mounting lens housings **130** to substrates **102**.

To illustrate, lens housing **130-1** is moved downwards to squeeze adhesive **302A1** between lens housing **130-1** and substrate **102**A. Adhesive **302A1** is cured, if necessary, thus mounting lens housing **130-1** to substrate **102**A. The other lens housings **130** are mounted to the other substrates **102** by adhesives **302**A in a similar manner.

FIG. **11** is a cross-sectional view of assembly **800** of FIG. **10** at a further stage during fabrication in accordance with one embodiment of the present invention. As shown in FIG. **11**, interconnection balls **126**, e.g., solder, are formed on pads **124**. To illustrate, interconnection ball **126**A is formed on pad **124**A. The other interconnection balls **126** are formed on the other pads **124** in a similar manner.

In one embodiment, each optical module **100** is tested for validity, i.e., to determine whether the optical module **100** is defective or not. Advantageously, testing optical modules **100** while still in an array format is less labor intensive and thus lower cost than testing each optical module **100** on an individual basis.

Image sensor substrate **802** is then singulated along singulation streets **812** to form a plurality of optical modules **100**. In this embodiment, image sensor substrate **802** is a snap straight substrate designed to be singulated by mechanically snapping along singulation streets **812**. To facilitate this snapping, image sensor substrate **802** is formed with snapping features along singulation streets **812** as discussed in greater detail below with reference to FIG. **12**A.

FIG. **12**A is an enlarged cross-sectional view of the region XII of image sensor substrate **802** of FIG. **9** during snapping in accordance with one embodiment of the present invention. Referring now to FIG. **12**A, a score **1202**, sometimes called a snapping feature, groove, trench, or cut, is formed along singulation street **812**A and between adjacent sidewalls **106** of adjacent substrates **102**. More particularly, score **1202** is formed between sidewall **106**A of substrate **102**A and sidewall **106**B of substrate **102**B. Score **1202** it is a V-shaped groove extending downwards from joint surfaces **106**J of sidewalls **106**A, **106**B.

To snap image sensor substrate **802**, image sensor substrate **802** is pressed upwards along singulation street **812**A as indicated by arrow **1204** and simultaneously pressed downwards along substrate **102**A and substrate **102**B as indicated by arrows **1206**. This bending force is concentrated at apex **1208** of score **1202** causing a crack **1210** to form along singulation street **812**A. In this manner, image sensor substrate **802** is singulated and, more particularly, substrate **102**A is singulated from substrate **102**B.

In accordance with this embodiment, a score **1220**, substantially identical to score **1202** but inverted, is also formed along singulation street **812**A. Score **1220** is formed between sidewall **106**A of substrate **102**A and sidewall **106**B of substrate **102**B. Score **1220** is an inverted V-shaped groove extending upwards from exterior surfaces **104**E of bases **104** of substrates **102**A, **102**B.

Score **1220** facilitate snapping of image sensor substrate **802** in a manner similar to that described above in regards to score **1202**. More particularly, score **1220** facilitate snapping of image sensor substrate **802** when pressed downwards along singulation street **812**A in a direction opposite arrow **1204** while simultaneously pressing upwards on substrates **102**A, **102**B in a direction opposite arrows **1206**. Although both scores **1202** and **1220** are illustrated in FIG. **12**A, in alternative embodiments, only score **1202** or **1220** is formed. In yet another alternative embodiment, neither score **1202** or score **1220** is formed. For example, image sensor substrate **802** is singulated by mechanical or laser sawing along singulation streets **812** and scores **1202**, **1220** are not formed.

FIG. **12**B is an enlarged cross-sectional view of the region XII of image sensor substrate **802** of FIG. **9** during snapping in accordance with another embodiment of the present invention. Referring now to FIG. **12**B, in accordance with this embodiment, through-holes **1230**, sometimes called snapping features, are formed, e.g., by drilling, along singulation street **812**A. Through-holes **1230** cause image sensor substrate **802** to have less mechanical strength along singulation street **812**A than along substrate **102**A or substrate **102**B. Accordingly, when image sensor substrate **802** is bent as indicated by arrows **1204**, **1206** (or opposite arrows **1204**, **1206**), image sensor substrate **802** snaps along singulation street **812**A thus singulating substrate **102**A from substrate **102**B.

In one embodiment, optical modules **100** are formed as LCC type modules. In accordance with this embodiment, interconnection balls **126** are not formed as illustrated in FIG. **11**. Instead, through-holes **1230** are lined with an electrically conductive material **1232**, which becomes an extension of exterior traces **120** on exterior surfaces **106**E of sidewalls **106**A, **106**B. More particularly, after snapping of image sensor substrate **802**, electrically conductive material **1232** remains along exterior surfaces **106**E of sidewalls **106**A, **106**B and forms extensions of exterior traces **120**.

In FIGS. **8**, **9**, **10** and **11**, mounting of lens housings **130** (FIG. **5**) to substrates **102** is illustrated. However, in alternative embodiments, lens housings **130**A (FIGS. **6**A, **6**B) or lens housings **130**B (FIG. **7**) are mounted to substrates **102** in a similar manner.

Forming a plurality of optical modules **100** simultaneously is less labor intensive, less complex, and thus less expensive than forming optical modules **100** on an individual basis. However, it is understood that optical modules **100** can also be fabricated individually, if desired.

This application is related to Webster et al., commonly assigned U.S. patent application Ser. No. 09/764,165, entitled "OPTICAL MODULE WITH LENS INTEGRAL HOLDER", now U.S. Pat. No. 6,686,588, issued Feb. 3, 2004, which is herein incorporated by reference in its entirety.

The drawings and the forgoing description gave examples of the present invention. The scope of the present invention, however, is by no means limited by these specific examples. Numerous variations, whether explicitly given in the specification or not, such as differences in structure, dimension, and use of material, are possible. The scope of the invention is at least as broad as given by the following claims.

What is claimed is:

1. An optical module comprising:

a substrate comprising:

a cavity;

a first interior surface;

a second interior surface formed around a periphery of the first interior surface and extending in a first direction from the first interior surface; and

a joint surface extending from the second interior surface;

an image sensor coupled in the cavity to the substrate, the image sensor being coupled to the first interior surface with an adhesive;

a lens housing coupled to the substrate, wherein the lens housing comprises a mounting surface comprising:

a first surface coupled to the joint surface; and

a second surface coupled to the second interior surface of the substrate; and

an electronic component on a first exterior surface of the substrate.

2. The optical module of claim **1** wherein the substrate comprises a cup shaped enclosure.

3. The optical module of claim **1** wherein a first surface of the image sensor is coupled to the first interior surface of the substrate with the adhesive.

4. The optical module of claim **3** wherein the image sensor comprises:

a second surface;

an active area on the second surface; and

bond pads on the second surface.

5. The optical module of claim **4** further comprising:

interior traces on the first interior surface of the substrate; and

bond wires electrically coupling the bond pads to the interior traces.

6. The optical module of claim **5** further comprising electrically conductive vias electrically coupled to the interior traces, the vias extending through the substrate from the first interior surface to the first exterior surface of the substrate.

7. The optical module of claim **6** further comprising exterior traces on the first exterior surface of the substrate, the exterior traces being electrically coupled to the vias.

8. The optical module of claim **7** wherein the exterior traces extend along a second exterior surface of the substrate.

9. The optical module of claim **5** further comprising electrically conductive pads on the first exterior surface of the substrate, the pads being electrically coupled to the interior traces.

10. The optical module of claim **5** further comprising electrically conductive interconnection balls on the first exterior surface of the substrate, the interconnection balls being electrically coupled to the interior traces.

11. The optical module of claim **4** wherein the lens housing comprises an internal cylindrical surface comprising a longitudinal axis perpendicular to the second surface of the image sensor.

12. The optical module of claim **11** wherein the internal cylindrical surface defines a central aperture, the optical module further comprising:

a lens support in the central aperture; and

an optical element coupled to the lens support.

13. The optical module of claim **1** further comprising an image sensor substrate comprising a plurality of substrates coupled together, the plurality of substrates comprising the substrate.

14. The optical module of claim **1** wherein the substrate is integral.

15. The optical module of claim **1** further comprising a second adhesive, the mounting surface being coupled to the joint surface by the second adhesive.

16. The optical module of claim **1** wherein the lens housing comprises a mounting rim comprising the mounting surface.

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